Appendix A to Part 420
Method for Defining a Flight Corridor

(a) Introduction

(1) This appendix provides a method for constructing a flight corridor from a launch point for a guided suborbital launch vehicle or any one of the four classes of guided orbital launch vehicles from table 1, § 420.19, without the use of local meteorological data or a launch vehicle trajectory.

(2) A flight corridor includes an overflight exclusion zone in a launch area and, for a guided suborbital launch vehicle, an impact dispersion area in a downrange area. A flight corridor for a guided suborbital launch vehicle ends with the impact dispersion area, and, for the four classes of guided orbital launch vehicles, 5000 nautical miles (nm) from the launch point.

(b) Data requirements

(1) Maps. An applicant shall use any map for the launch site region with a scale not less than 1:250,000 inches per inch in the launch area and 1:20,000,000 inches per inch in the downrange area. As described in paragraph (b)(2), an applicant shall use a mechanical method, a semi-automated method, or a fully-automated method to plot a flight corridor on maps. A source for paper maps acceptable to the FAA is the U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service.

(i) Projections for mechanical plotting method. An applicant shall use a conic projection. The FAA will accept a "Lambert-Conformal" conic projection. A polar aspect of a plane-azimuthal projection may also be used for far northern launch sites.

(ii) Projections for semi-automated plotting method. An applicant shall use cylindrical, conic, or plane projections for semi-automated plotting. The FAA will accept "Mercator" and "Oblique Mercator" cylindrical projections. The FAA will accept "Lambert-Conformal" and "Albers Equal-Area" conic projections. The FAA will accept "Lambert Azimuthal Equal-Area" and "Azimuthal Equidistant" plane projections.

(iii) Projections for fully-automated plotting method. The FAA will accept map projections used by geographical information system software scaleable pursuant to the requirements of paragraph (b)(1).

(2) Plotting Methods.

(i) Mechanical method. An applicant may use mechanical drafting equipment such as pencil, straight edge, ruler, protractor, and compass to plot the location of a flight corridor on a map. The FAA will accept straight lines for distances less than or equal to 7.5 times the map scale on map scales greater than or equal to 1:1,000,000 inches per inch (in/in); or straight lines representing 100 nm or less on map scales less than 1:1,000,000 in/in.

(ii) Semi-automated method. An applicant may employ the range and bearing techniques in paragraph (b)(3) to create latitude and longitude points on a map. The FAA will accept straight lines for distances less than or equal to 7.5 times the map scale on map scales greater than or equal to 1:1,000,000 inches per inch (in/in); or straight lines representing 100 nm or less on map scales less than 1:1,000,000 in/in.

(iii) Fully-automated method. An applicant may use geographical information system software with global mapping data scaleable in accordance with paragraph (b)(1).

(3) Range and bearing computations on an ellipsoidal Earth model.

(i) To create latitude and longitude pairs on an ellipsoidal Earth model, an applicant shall use the following equations to calculate geodetic latitude (+N) and longitude (+E) given the launch point geodetic latitude (+N), longitude (+E), range (nm), and bearing (degrees, positive clockwise from North).

(A) Input. An applicant shall use the following input in making range and bearing computations. Angle units must be in radians.

$$f_1 = \text{Geodetic latitude of launch point (radians)}$$

$$= f_1\ (\text{DDD}) \cdot \frac{p}{180} (\text{radians per degree})$$

$$l_1 = \text{Longitude of launch point (DDD)}$$

$$= l_1\ (\text{DDD}) \cdot \frac{p}{180} (\text{radians per degree})$$

$$\text{S} = \text{Range from launch point (nm)}$$

$$= \text{S}\ (\text{DDD}) \cdot \frac{p}{180} (\text{radians per degree})$$

$$a_{12} = \text{Azimuth bearing from launch point (deg)}$$

$$= a_{12}\ (\text{DDD}) \cdot \frac{p}{180} (\text{radians per degree})$$

(B) Computations. An applicant shall use the following equations to determine the latitude (ϕ_2) and longitude (λ_2) of a target point situated "S" nm from the launch point on an azimuth bearing α_{12} degrees.

$$f = 1 - \frac{b}{a} \qquad \text{(Equation A1)}$$

where:

a = WGS - 84 semi - major axis (3443.91846652 nmi)

b = WGS - 84 semi - minor axis (3432.37165994 nmi)

$$\varepsilon^2 = \frac{\left(a^2 - b^2\right)}{b^2} \qquad \text{(Equation A2)}$$

$$\theta = \frac{S}{b} \text{ (radians)} \qquad \text{(Equation A3)}$$

$$\beta_1 = \tan^{-1}\left[\frac{(b \cdot \sin\phi_1)}{(a \cdot \cos\phi_1)}\right] \qquad \text{(Equation A4)}$$

$$g = (\cos\beta_1)(\cos\alpha_{12}) \qquad \text{(Equation A5)}$$

$$h = (\cos\beta_1)(\sin\alpha_{12}) \qquad \text{(Equation A6)}$$

$$m = \frac{\left[1 + \left(\frac{\varepsilon^2}{2}\right)\sin^2\beta_1\right]\left[1 - h^2\right]}{2} \qquad \text{(Equation A7)}$$

$$n = \frac{\left[1 + \left(\frac{\varepsilon^2}{2}\right)\sin^2\beta_1\right]\left[\left(\sin^2\beta_1\right)(\cos\theta) + g \cdot (\sin\beta_1)(\sin\theta)\right]}{2} \qquad \text{(Equation A8)}$$

$$L = h \cdot \left[-f \cdot \theta + 3 \cdot f^2 \cdot n \cdot \sin\theta + \frac{3 \cdot f^2 \cdot m \cdot (\theta - \sin\theta \cdot \cos\theta)}{2}\right] \text{ (radians)} \qquad \text{(Equation A9)}$$

$$M = m \cdot \varepsilon^2 \qquad \text{(Equation A10)}$$

$$N = n \cdot \varepsilon^2 \qquad \text{(Equation A11)}$$

$$A_1 = N \cdot \sin\theta \qquad \text{(Equation A12)}$$

$$A_2 = \left(\frac{M}{2}\right)(\sin\theta \cdot \cos\theta - \theta) \qquad \text{(Equation A13)}$$

$$A_3 = \left(\frac{5}{2}\right)\left(N^2 \cdot \sin\theta \cdot \cos\theta\right) \qquad \text{(Equation A14)}$$

$$A_4 = \left(\frac{M^2}{16}\right)\left(11 \cdot \theta - 13 \cdot \sin\theta \cdot \cos\theta - 8 \cdot \theta \cdot \cos^2\theta + 10 \cdot \sin\theta \cdot \cos^3\theta\right)$$

(Equation A15)

$$A_5 = \left(\frac{M \cdot N}{2}\right)\left(3 \cdot \sin\theta + 2 \cdot \theta \cdot \cos\theta - 5 \cdot \sin\theta \cdot \cos^2\theta\right)$$ (Equation A16)

$$\delta = \theta - A_1 + A_2 + A_3 + A_4 + A_5 \text{ (radians)}$$ (Equation A17)

$$\sin\beta_2 = \sin\beta_1 \cdot \cos\delta + g \cdot \sin\delta$$ (Equation A18)

$$\cos\beta_2 = \left[h^2 + \left(g \cdot \cos\delta - \sin\beta_1 \cdot \sin\delta\right)^2\right]^{\frac{1}{2}}$$ (Equation A19)

$$\phi_2 = \left\{\tan^{-1}\left[\frac{(a \cdot \sin\beta_2)}{(b \cdot \cos\beta_2)}\right]\right\} \cdot \left(\frac{180}{\pi}\right) \text{ (geodetic latitude of target point, DDD)}$$

(Equation A20)

$$\Lambda = \tan^{-1}\left[\frac{(\sin\delta \cdot \sin\alpha_{12})}{(\cos\beta_1 \cdot \cos\delta - \sin\beta_1 \cdot \sin\delta \cdot \cos\alpha_{12})}\right]$$ (Equation A21)

$$\lambda_2 = (\lambda_1 + \Lambda + L)\left(\frac{180}{\pi}\right) \text{ (longitude of target point, DDD)}$$ (Equation A22)

(ii) To create latitude and longitude pairs on an ellipsoidal Earth model, an applicant shall use the following equations to calculate the distance (S) of the geodesic between two points (P_1 and P_2), the forward azimuth (α_{12}) of the geodesic at P_1, and the back azimuth (α_{21}) of the geodesic at P_2, given the geodetic latitude (+N), longitude (+E) of P_1 and P_2. Azimuth is measured positively clockwise from North.

(A) Input. An applicant shall use the following input. Units must be in radians.

$$f_1 = \text{Geodetic latitude of launch point (radians)}$$

$$= f_1 \text{ (DDD)} \cdot \frac{p}{180} \text{(radians per degree)}$$

$$l_1 = \text{Longitude of launch point (DDD)}$$

$$= l_1 \text{ (DDD)} \cdot \frac{p}{180} \text{(radians per degree)}$$

$$\text{S} = \text{Range from launch point (nm)}$$

$$= \text{S (DDD)} \cdot \frac{p}{180} \text{(radians per degree)}$$

$$\boldsymbol{a}_{12} = \text{Azimuth bearing from launch point (deg)}$$

$$= \boldsymbol{a}_{12} \text{ (DDD)} \cdot \frac{p}{180} \text{(radians per degree)}$$

(B) Computations. An applicant shall use the following equations to determine the distance (S), the forward azimuth (α_{12}) of the geodesic at P_1, and the back azimuth (α_{21}) of the geodesic at P_2.

$$\text{f} = 1 - \frac{\text{b}}{\text{a}} \qquad \text{(Equation A23)}$$

where:

$$a = \text{ WGS - 84 semi - major axis (3443.91846652 nmi)}$$

$$\text{b} = \text{ WGS - 84 semi - minor axis (3432.37165994 nmi)}$$

$$\text{L} = \text{l}_2 - \text{l}_1 \qquad \text{(Equation A24)}$$

$$b_1 = \tan^{-1}\left[\frac{(b \cdot \sin f_1)}{a \cdot \cos f_1}\right] \qquad \text{(Equation A25)}$$

$$b_2 = \tan^{-1}\left[\frac{(b \cdot \sin f_2)}{a \cdot \cos f_2}\right] \qquad \text{(Equation A26)}$$

$$\text{A} = \sin \text{b}_1 \times \sin \text{b}_2 \qquad \text{(Equation A27)}$$

$$\text{B} = \cos \text{b}_1 \times \cos \text{b}_2 \qquad \text{(Equation A28)}$$

$$\cos \text{d} = \text{A} + \text{B} \times \cos \text{L} \qquad \text{(Equation A29)}$$

$$n = \frac{(a-b)}{(a+b)} \qquad \text{(Equation A30)}$$

$$(b_2 - b_1) = (f_2 - f_1) + 2 \cdot \left[A \cdot (n + n^2 + n^3) - B \cdot (n - n^2 + n^3) \right] \cdot \sin(f_2 - f_1) \text{ radians}$$

(Equation A31)

$$\sin d = \left\{ \begin{array}{l} (\sin L \cdot \cos b_2)^2 + \\ \left[\sin(b_2 - b_1) + 2 \cdot \cos b_2 \cdot \sin b_1 \cdot \sin^2(L/2) \right]^2 \end{array} \right\}^{\frac{1}{2}}$$ (Equation A32)

$$d = \tan^{-1}\left(\frac{\sin d}{\cos d} \right) \text{ evaluated in positive radians } \leq p$$ (Equation A33)

$$c = \frac{B \times \sin L}{\sin d}$$ (Equation A34)

$$m = 1 - c^2$$ (Equation A35)

$$S = b \cdot \left\{ \begin{array}{l} d \cdot [1 + f + f^2] + A \cdot \left[(f + f^2) \cdot \sin d - (f^2 \cdot d^2)/(2 \cdot \sin d) \right] \\ -(m/2)\left[(f + f^2)(d + \sin d \cdot \cos d) - (f^2 \cdot d^2)/(\tan d) \right] \\ -(A^2 \cdot f^2/2) \cdot \sin d \cdot \cos d \\ +(f^2 \cdot m^2/16)\left[d + \sin d \cdot \cos d - 2 \cdot \sin d \cdot \cos^3 d - 8d^2/(\tan d) \right] \\ +(A^2 \cdot m \cdot f^2/2)\left[\sin d \cdot \cos^2 d + d^2/(\sin d) \right] \end{array} \right\}$$

in the same units as "a" and "b"

(Equation A36)

$$\Lambda = L + c \cdot \left\{ \begin{array}{l} d \cdot (f + f^2) - (A \cdot f^2/2)\left[\sin d + 2d^2/(\sin d) \right] \\ + (m \cdot f^2/4)\left[\sin d \cos d - 5d + 4d^2/(\tan d) \right] \end{array} \right\} \text{ radians}$$ (Equation A37)

$$a_{12} = \tan^{-1}\left\{ \frac{(\cos b_2 \cdot \sin \Lambda)}{\left[\sin(b_2 - b_1) + 2 \cdot \cos b_2 \cdot \sin b_1 \cdot \sin^2(\Lambda/2) \right]} \right\} \cdot \left(\frac{180}{p} \right) \text{ degrees}$$

(Equation A38)

$$a_{21} = \tan^{-1}\left\{ \frac{(-\cos b_1 \cdot \sin \Lambda)}{\left[2 \cdot \cos b_1 \cdot \sin b_2 \cdot \sin^2(\Lambda/2) - \sin(b_2 - b_1) \right]} \right\} \cdot \left(\frac{180}{p} \right) \text{ degrees}$$

(Equation A39)

(c) Creation of a flight corridor

(1) To define a flight corridor, an applicant shall:

(i) Select a guided suborbital or orbital launch vehicle, and, for an orbital launch vehicle, select from table 1 of § 420.19 a launch vehicle weight class that best represents the launch vehicle the applicant plans to support at its launch point;

(ii) Select a debris dispersion radius (D_{max}) from table A-1 corresponding to the guided suborbital launch vehicle or orbital launch vehicle class selected in paragraph (c)(1)(i);

(iii) Select a launch point geodetic latitude and longitude; and

(iv) Select a flight azimuth.

(2) An applicant shall define and map an overflight exclusion zone using the following method:

(i) Select a debris dispersion radius (D_{max}) from table A-1 and a downrange distance (D_{OEZ}) from table A-2 to define an overflight exclusion zone for the guided suborbital launch vehicle or orbital launch vehicle class selected in paragraph (c)(1)(i).

(ii) An overflight exclusion zone is described by the intersection of the following boundaries, which are depicted in figure A-1:

(A) An applicant shall define an uprange boundary with a half-circle arc of radius D_{max} and a chord of length twice D_{max} connecting the half-circle arc endpoints. The uprange boundary placement on a map has the chord midpoint positioned on the launch point with the chord oriented along an azimuth ±90° from the launch azimuth and the half-circle arc located uprange from the launch point.

(B) An applicant shall define the downrange boundary with a half-circle arc of radius D_{max} and a chord of length twice D_{max} connecting the half-circle arc endpoints. The downrange boundary placement on a map has the chord midpoint intersecting the nominal flight azimuth line at a distance D_{OEZ} inches downrange with the chord oriented along an azimuth ±90° from the launch azimuth and the half-circle arc located downrange from the intersection of the chord and the flight azimuth line.

(C) Crossrange boundaries of an overflight exclusion zone are defined by two lines segments. Each is parallel to the flight azimuth with one to the left side and one to the right side of the flight azimuth line. Each line connects an uprange half-circle arc endpoint to a downrange half-circle arc endpoint as shown in figure A-1.

(iii) An applicant shall identify the overflight exclusion zone on a map that meets the requirements of paragraph (b).

(3) An applicant shall define and map a flight corridor using the following method:

(i) In accordance with paragraph (b), an applicant shall draw a flight corridor on one or more maps with the D_{max} origin centered on the intended launch point and the flight corridor centerline (in the downrange direction) aligned with the initial flight azimuth. The flight corridor is depicted in figure A-2 and its line segment lengths are tabulated in table A-3.

(ii) An applicant shall define the flight corridor using the following boundary definitions:

(A) An applicant shall draw an uprange boundary, which is defined by an arc-line GB (figure A-2), directly uprange from and centered on the intended launch point with radius $D_{max.}$

(B) An applicant shall draw line CF perpendicular to and centered on the flight azimuth line, and positioned 10 nm downrange from the launch point. The applicant shall use the length of line CF provided in table A-3 corresponding to the guided suborbital launch vehicle or orbital launch vehicle class selected in paragraph (c)(1)(i).

(C) An applicant shall draw line DE perpendicular to and centered on the flight azimuth line, and positioned 100 nm downrange from the launch point. The applicant shall use the length of line DE provided in table A-3 corresponding to the guided suborbital launch vehicle or orbital launch vehicle class selected in paragraph (c)(1)(i).

(D) Except for a guided suborbital launch vehicle, an applicant shall draw a downrange boundary, which is defined by line HI and is drawn perpendicular to and centered on the flight azimuth line, and positioned 5,000 nm downrange from the launch point. The applicant shall use the length of line HI provided in table A-3 corresponding to the orbital launch vehicle class selected in paragraph (c)(1)(i).

(E) An applicant shall draw crossrange boundaries, which are defined by three lines on the left side and three lines on the right side of the flight azimuth. An applicant shall construct the left flight corridor boundary according to the following, and as depicted in figure A-3 :

(*1*) The first line (line BC in figure A-3) is tangent to the uprange boundary arc, and ends at endpoint C of line CF, as depicted in figure A-3;

(*2*) The second line (line CD in figure A-3) begins at endpoint C of line BC and ends at endpoint D of line DH, as depicted in figure A-3;

(*3*) For all orbital launch vehicles, the third line (line DH in figure A-3) begins at endpoint D of line CD and ends at endpoint H of line HI, as depicted in figure A-3; and

(*4*) For a guided suborbital launch vehicle, the line DH begins at endpoint D of line CD and ends at a point tangent to the impact dispersion area drawn in accordance with paragraph (c)(4) and as depicted in figure A-4.

(F) An applicant shall repeat the procedure in paragraph (c)(3)(ii)(E) for the right side boundary.

(iii) An applicant shall identify the flight corridor on a map that meets the requirements of paragraph (b).

(4) For a guided suborbital launch vehicle, an applicant shall define a final stage impact dispersion area as part of the flight corridor and show the impact dispersion area on a map, as depicted in figure A-4, in accordance with the following:

(i) An applicant shall select an apogee altitude (H_{ap}) for the launch vehicle final stage. The apogee altitude should equal the highest altitude intended to be reached by a guided suborbital launch vehicle launched from the launch point.

(ii) An applicant shall define the impact dispersion area by using an impact range factor [$IP(H_{ap})$] and a dispersion factor [$DISP(H_{ap})$] as shown below:

(A) An applicant shall calculate the impact range (D) for the final launch vehicle stage. An applicant shall set D equal to the maximum apogee altitude (H_{ap}) multiplied by the impact range factor as shown below:

$$\mathrm{D} = \mathrm{H}_{\mathrm{ap}} \cdot IP\left(H_{ap}\right) \qquad \text{(Equation A40)}$$

where: $IP(H_{ap})$ = 0.4 for an apogee less than 100 km; and
$IP(H_{ap})$ = 0.7 for an apogee 100 km or greater.

(B) An applicant shall calculate the impact dispersion radius (R) for the final launch vehicle stage. An applicant shall set R equal to the maximum apogee altitude (H_{ap}) multiplied by the dispersion factor as shown below:

$$R = H_{ap} \cdot DISP\left(H_{ap}\right) \qquad \text{(Equation A41)}$$

where: $DISP(H_{ap})$ = 0.05

(iii) An applicant shall draw the impact dispersion area on a map with its center on the predicted impact point. An applicant shall then draw line DH in accordance with paragraph (c)(3)(ii)(E)(4).

(d) Evaluate the flight corridor

(1) An applicant shall evaluate the flight corridor for the presence of any populated areas. If an applicant determines that no populated area is located within the flight corridor, then no additional steps are necessary.

(2) If a populated area is located in an overflight exclusion zone, an applicant may modify its proposal or demonstrate that there are times when no people are present or that the applicant has an agreement in place to evacuate the public from the overflight exclusion zone during a launch.

(3) If a populated area is located within the flight corridor, an applicant may modify its proposal and create another flight corridor pursuant to appendix A, use appendix B to narrow the flight corridor, or complete a risk analysis in accordance with appendix C.

Table A-1: Debris Dispersion Radius (D_{max}) (in)

Orbital Launch Vehicles				Suborbital Launch Vehicles
Small	Medium	Medium Large	Large	Guided
87,600 (1.20 nm)	111,600 (1.53 nm)	127,200 (1.74 nm)	156,000 (2.14 nm)	96,000 (1.32 nm)

Table A-2: Overflight Exclusion Zone Downrange Distance (D_{OEZ}) (in)

Orbital Launch Vehicles				Suborbital Launch Vehicles
Small	Medium	Medium Large	Large	Guided
240,500 (3.30 nm)	253,000 (3.47 nm)	310,300 (4.26 nm)	937,700 (12.86 nm)	232,100 (3.18 nm)

Table A-3: Flight Corridor Line Segment Lengths

D_{max} (in)		Line Segment Lengths (x 10^6 inches)		
Orbital Launch Vehicles		$\overline{CF}$	$\overline{DE}$	$\overline{HI}$
Small	87600 (1.20 nm)	2.87620 (39.45 nm)	8.59452 (117.87 nm)	128.566 (1763.27 nm)
Medium	111,600 (1.53 nm)	2.97220 (40.76 nm)	8.64252 (118.53 nm)	128.566 (1763.27 nm)
Med-Large	127,200 (1.74 nm)	3.03460 (41.62 nm)	8.67372 (118.96 nm)	128.566 (1763.27 nm)
Large	156,000 (2.14 nm)	3.14979 (43.20 nm)	8.73131 (119.75 nm)	128.566 (1763.27 nm)
Suborbital Launch Vehicles		$\overline{CF}$	$\overline{DE}$	$\overline{HI}$
Guided	96,000 (1.32 nm)	2.90980 (39.91 nm)	8.61132 (118.10 nm)	N/A

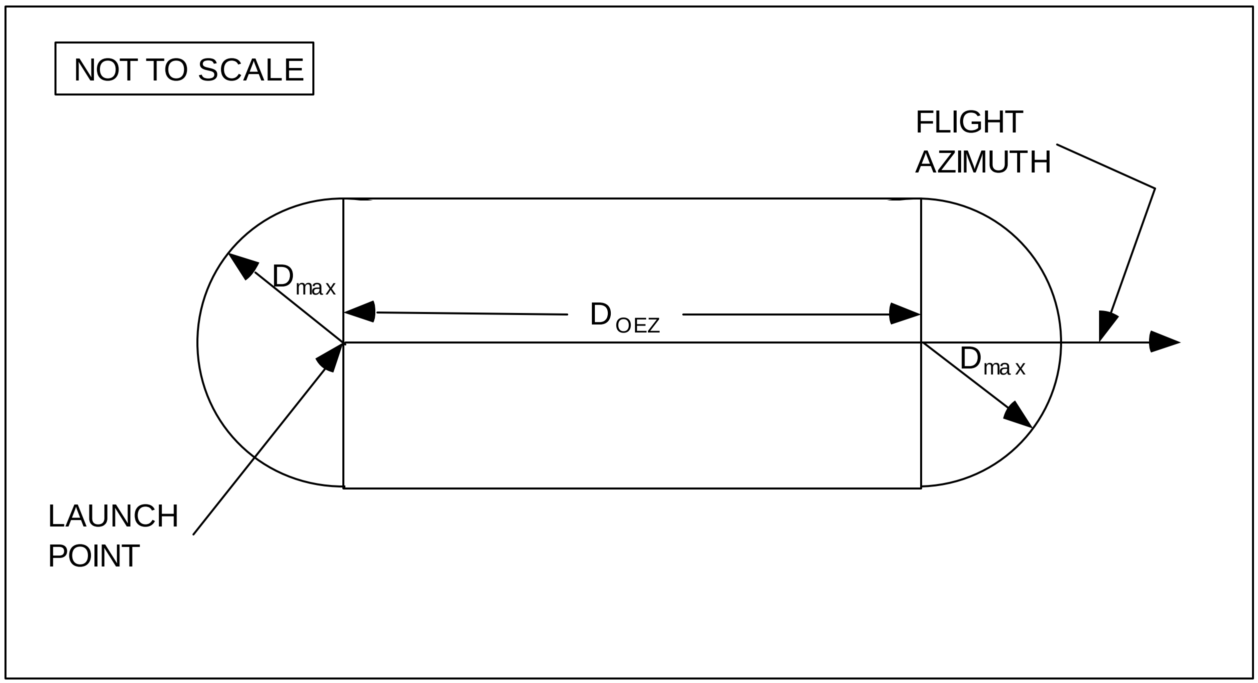

Figure A-1
Overflight Exclusion Zone

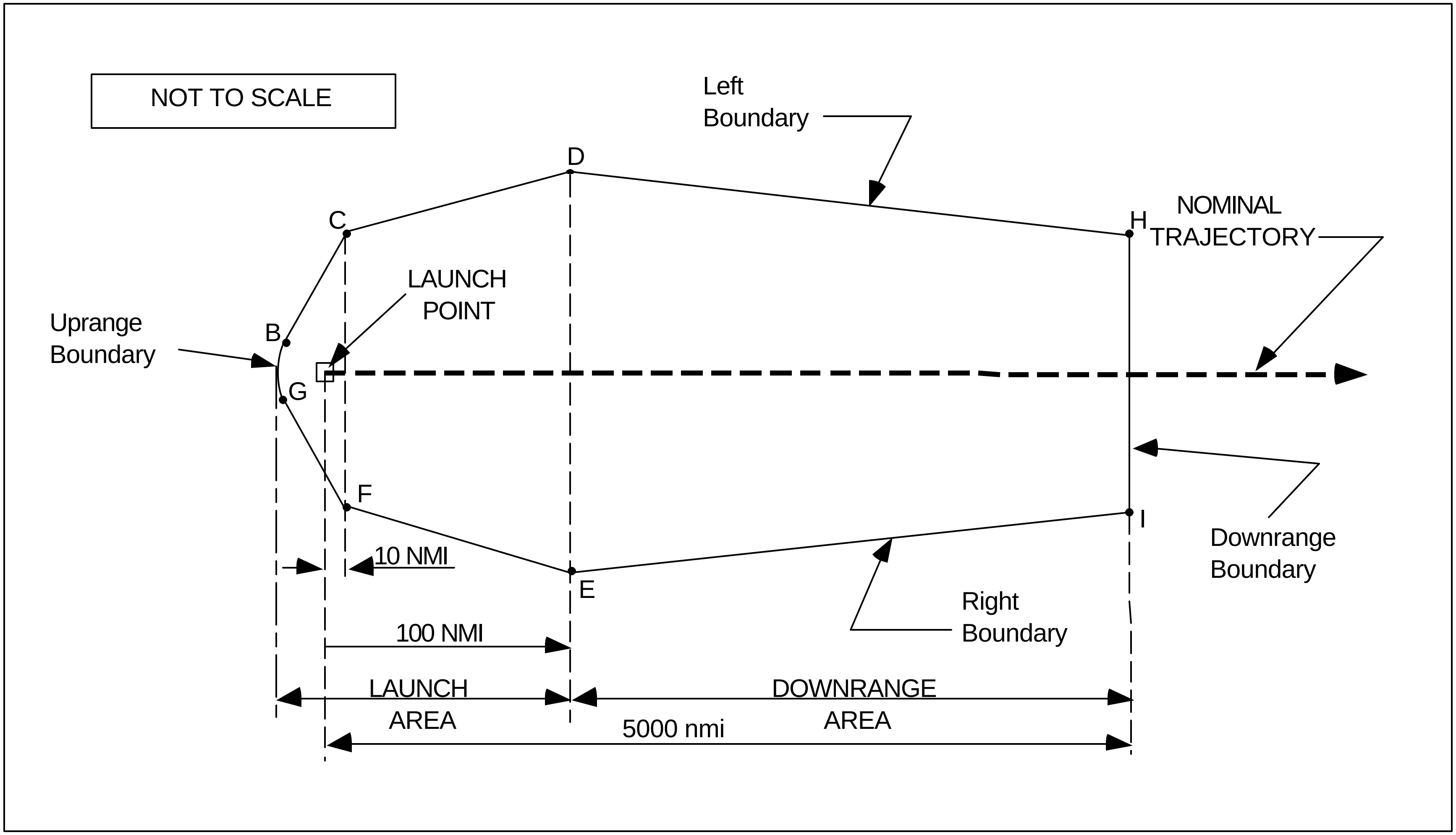

Figure A-2
Flight Corridor

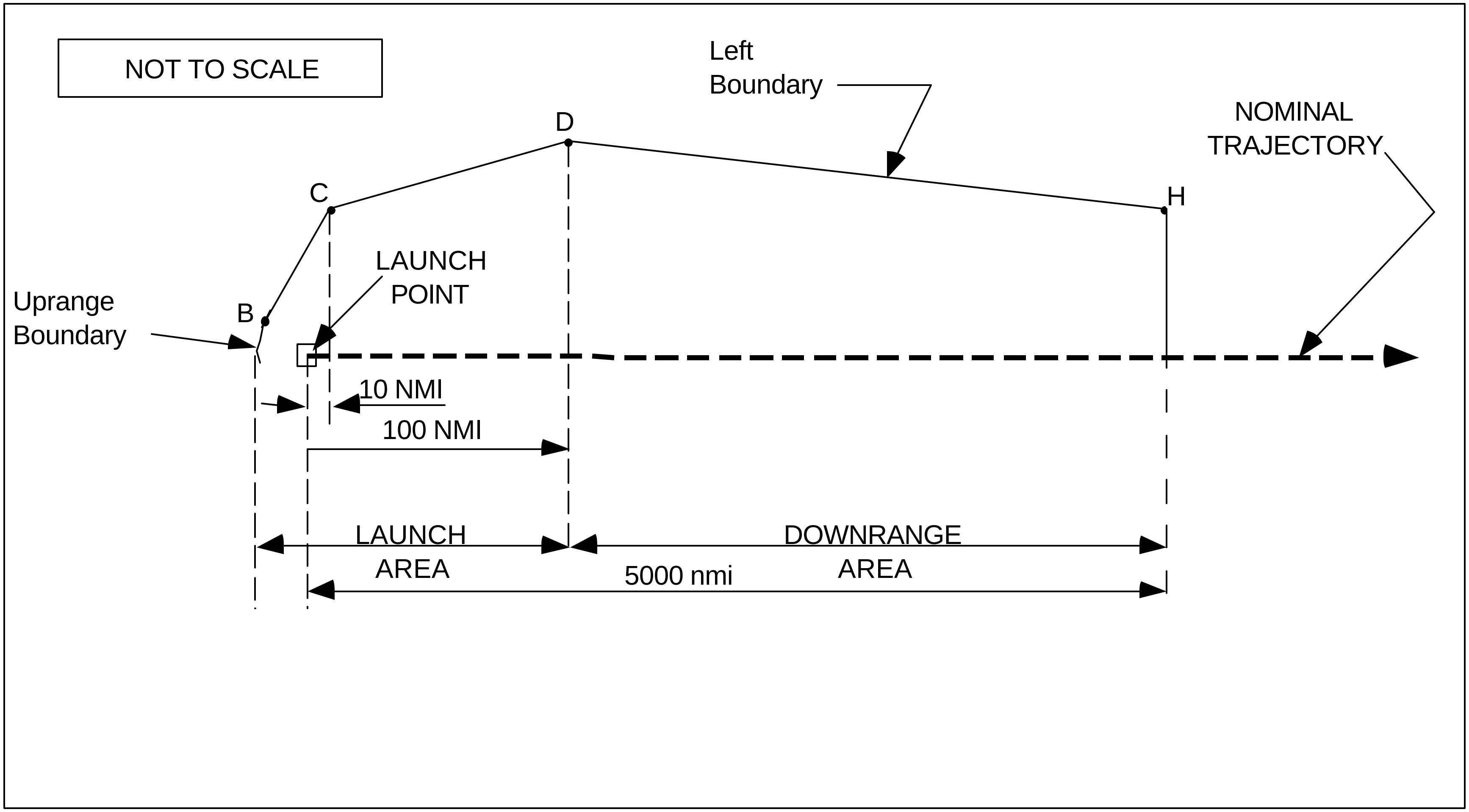

Figure A-3
Construction of Left Boundary of Flight Corridor

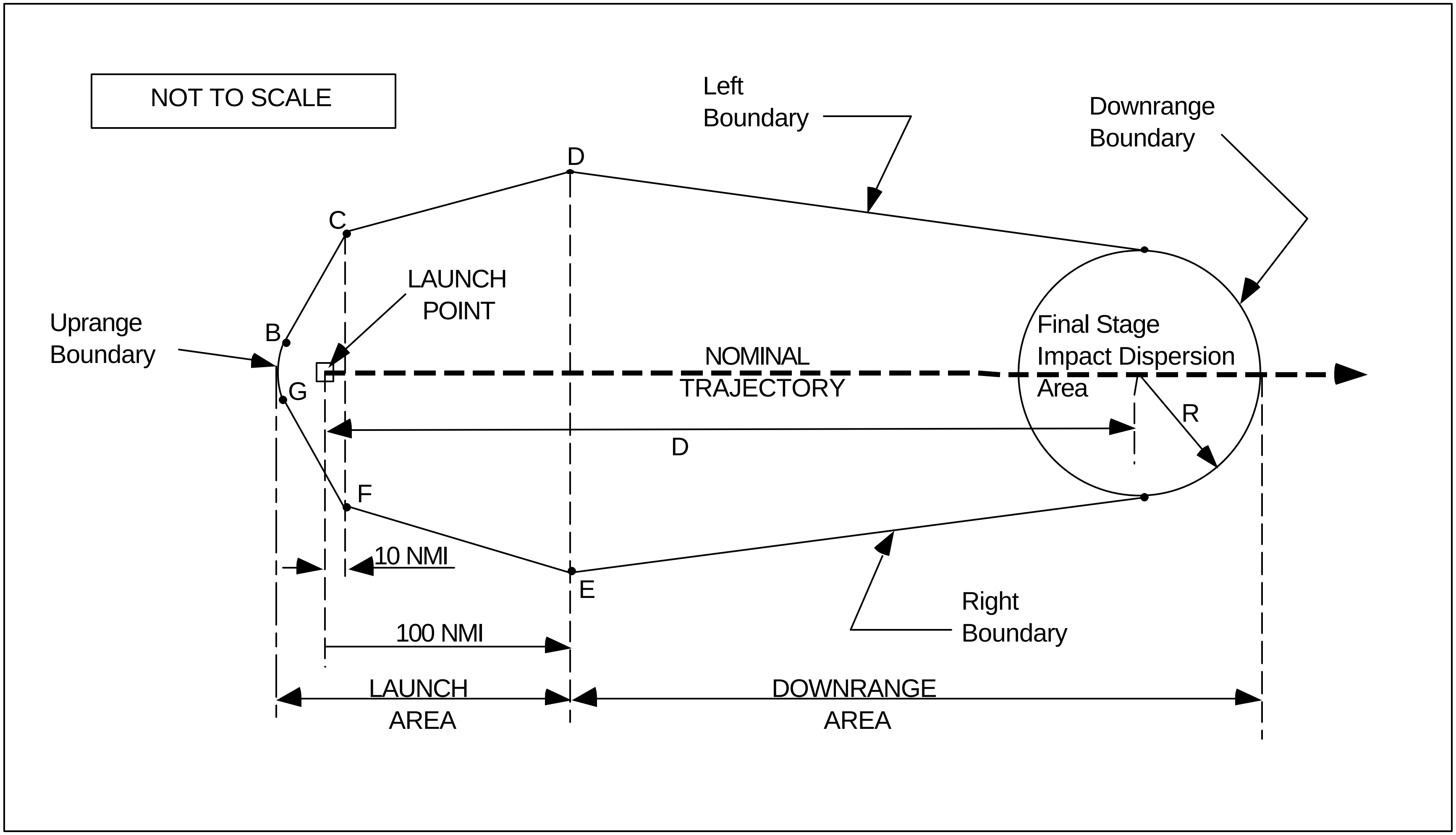

Figure A-4
Flight Corridor for Guided Sub-Orbital Launch Vehicles

Appendix B to Part 420
Method for Defining a Flight Corridor

(a) Introduction

(1) This appendix provides a method to construct a flight corridor from a launch point for a guided suborbital launch vehicle or any one of the four weight classes of guided orbital launch vehicles from table 1, § 420.19, using local meteorological data and a launch vehicle trajectory.

(2) A flight corridor is constructed in two sections — one section comprising a launch area and one section comprising a downrange area. The launch area of a flight corridor reflects the extent of launch vehicle debris impacts in the event of a launch vehicle failure and applying local meteorological conditions. The downrange area reflects the extent of launch vehicle debris impacts in the event of a launch vehicle failure and applying vehicle imparted velocity, malfunctions turns, and vehicle guidance and performance dispersions.

(3) A flight corridor includes an overflight exclusion zone in the launch area and, for a guided suborbital launch vehicle, an impact dispersion area in the downrange area. A flight corridor for a guided suborbital launch vehicle ends with an impact dispersion area and, for the four classes of guided orbital launch vehicles, 5,000 nautical miles (nm) from the launch point, or where the IIP leaves the surface of the Earth, whichever is shorter.

(b) Data requirements

(1) Launch area data requirements. An applicant shall satisfy the following data requirements to perform the launch area analysis of this appendix. The data requirements are identified in table B-1 along with sources where data acceptable to the FAA may be obtained.

(i) An applicant must select meteorological data that meet the specifications in table B-1 for the proposed launch site.

Table B-1. Launch Area Data Requirements

Data Category	Data Item	Data Source
Meteorological Data	Local statistical wind data as a function of altitude up to 50,000 feet. Required data include: altitude (ft), atmospheric density (slugs/ft^3), mean East/West meridianal (u) and North/South zonal (v) wind (ft/sec), standard deviation of u and v wind (ft/sec), correlation coefficient, number of observations and wind percentile (%).	These data may be obtained from: Global Gridded Upper Air Statistics, Climate Applications Branch National Climatic Data Center
Nominal Trajectory Data	State vector data as function of time after liftoff in topocentric launch point centered $X, Y, Z, \dot{X}, \dot{Y}, \dot{Z}$ coordinates with the X-axis aligned with the flight azimuth. Trajectory time intervals shall not be greater than one second. XYZ units are in feet and $\dot{X}, \dot{Y}, \dot{Z}$ units are in ft/sec.	Actual launch vehicle trajectory data; or trajectory generation software that meets the requirements of paragraph (b)(1)(ii).
Debris Data	A fixed ballistic coefficient equal to 3 lbs/ft^2 is used for the launch area.	N/A
Geographical Data	Launch point geodetic latitude on a WGS-84 ellipsoidal Earth model	Geographical surveys or Global Positioning System
	Launch point longitude on an ellipsoidal Earth model	
	Maps using scales of not less than 1:250,000 inches per inch within 100 nm of a launch point and 1:20,000,000 inches per inch for distances greater than 100 nm from a launch point	Map types with scale and projection information are listed in the Defense Mapping Agency, Public Sale, Aeronautical Charts and Publications Catalog. The catalog and maps may be ordered through the U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service

(ii) For a guided orbital launch vehicle, an applicant shall obtain or create a launch vehicle nominal trajectory. An applicant may use trajectory data from a launch vehicle manufacturer or generate a trajectory using trajectory simulation software. Trajectory time intervals shall be no greater than one second. If an applicant uses a trajectory computed with commercially available software, the software must calculate the trajectory using the following parameters, or clearly and convincingly demonstrated equivalents:

(A) Launch location:

(*1*) Launch point, using geodetic latitude and longitude to four decimal places; and

(2) Launch point height above sea level.

(B) Ellipsoidal Earth:

(1) Mass of Earth;

(*2*) Radius of Earth;

(*3*) Earth flattening factor; and

(*4*) Gravitational harmonic constants (J2, J3, J4).

(C) Vehicle characteristics:

(1) Mass as a function of time;

(2) Thrust as a function of time;

(3) Specific impulse (I_{SP}) as a function of time; and

(4) Stage dimensions.

(D) Launch events:

(*1*) Stage burn times; and

(*2*) Stage drop-off times.

(E) Atmosphere:

(*1*) Density as a function of altitude;

(*2*) Pressure as a function of altitude;

(*3*) Speed of sound as a function of altitude; and

(*4*) Temperature as a function of altitude.

(F) Winds:

(*1*) Wind direction as a function of altitude; and

(*2*) Wind magnitude as a function of altitude.

(I) Aerodynamics: drag coefficient as a function of mach number for each stage of flight showing subsonic, transonic and supersonic mach regions for each stage.

(iii) An applicant shall use a ballistic coefficient (b) of 3 lbs/ft^2 for debris impact computations.

(iv) An applicant shall satisfy the map and plotting requirements for a launch area of appendix A, paragraph (b).

(2) Downrange area data requirements. An applicant shall satisfy the following data requirements to perform the downrange area analysis of this appendix.

(i) The launch vehicle weight class and method of generating a trajectory used in the launch area shall be used by an applicant in the downrange area as well. Trajectory time intervals must not be greater than one second.

(ii) An applicant shall satisfy the map and plotting data requirements for a downrange area of appendix A, paragraph (b).

(c) Construction of a launch area of a flight corridor

(1) An applicant shall construct a launch area of a flight corridor using the processes and equations of this paragraph for each trajectory position. An applicant shall repeat these processes at time points on the launch vehicle trajectory for time intervals of no greater than one second. When choosing wind data, an applicant shall use a time period of between one and 12 months.

(2) A launch area analysis must include all trajectory positions whose Z-values are less than or equal to 50,000 ft.

(3) Each trajectory time is denoted by the subscript “i”. Height intervals for a given atmospheric pressure level are denoted by the subscript “j”.

(4) Using data from the GGUAS CD-ROM, an applicant shall estimate the mean atmospheric density, maximum wind speed, height interval fall times and height interval debris dispersions for 15 mean geometric height intervals.

(i) The height intervals in the GGUAS source data vary as a function of the following 15 atmospheric pressure levels expressed in millibars: surface, 1000, 850, 700, 500, 400, 300, 250, 200, 150, 100, 70, 50, 30, 10. The actual geometric height associated with each pressure level varies depending on the time of year. An applicant shall estimate the mean geometric height over the period of months selected in subparagraph (1) of this paragraph for each of the 15 pressure levels as shown in equation B1.

$$\overline{H}_j = \frac{\sum_{m=1}^{k} h_m \cdot n_m}{\sum_{m=1}^{k} n_m} \qquad \text{(Equation B1)}$$

where: $\overline{H}_j$ = mean geometric height
h_m = geometric height for a given month
n_m = number of observations for a given month
k = number of wind months of interest

(ii) The atmospheric densities in the source data also vary as a function of the 15 atmospheric pressure levels. The actual atmospheric density associated with each pressure level varies depending on the time of year. An applicant shall estimate the mean atmospheric density over the period of months selected in accordance with subparagraph (1) of this paragraph for each of the 15 pressure levels as shown in equation B2.

$$\overline{\rho}_j = \frac{\sum_{m=1}^{k} \rho_m \cdot n_m}{\sum_{m=1}^{k} n_m} \qquad \text{(Equation B2)}$$

where: $\overline{\rho}_j$ = mean atmospheric density
ρ_m = atmospheric density for a given month
n_m = number of observations for a given month
k = number of wind months of interest

(iii) An applicant shall estimate the algebraic maximum wind speed at a given pressure level as follows and shall repeat the process for each pressure level.

(A) For each month, an applicant shall calculate the monthly mean wind speed ($\overline{w}_{az}$) for 360 azimuths using equation B3;

(B) An applicant shall select the maximum monthly mean wind speed from the 360 azimuths;

(C) An applicant shall repeat subparagraphs (c)(4)(iii)(A) and (B) for each month of interest; and

(D) An applicant shall select the maximum mean wind speed from the range of months. The absolute value of this wind is designated W_{max} for the current pressure level.

(iv) An applicant shall calculate wind speed using the means for winds from the West (u) and winds from the North (v). An applicant shall use equation B3 to resolve the winds to a specific azimuth bearing.

$$\overline{W}_{az} = u \cdot \cos(90 - az) + v \cdot \sin(90 - az) \qquad \text{(Equation B3)}$$

where: az = wind azimuth
u = West zonal wind component
v = North zonal wind component
$\overline{W}_{az}$ = mean wind speed at azimuth for each month

(v) An applicant shall estimate the interval fall time over a height interval assuming the initial descent velocity is equal to the terminal velocity (V_T). An applicant shall use equations B4 through B6 to estimate the fall time over a given height interval.

$$\Delta H_j = \overline{H}_{j+1} - \overline{H}_j \qquad \text{(Equation B4)}$$

$$V_{Tj} = \left[\frac{2 \cdot \beta}{\frac{\left(\overline{\rho}_{j+1} + \overline{\rho}_j\right)}{2}} \right]^{0.5} \qquad \text{(Equation B5)}$$

$$t_j = \frac{\Delta H_j}{V_{Tj}} \qquad \text{(Equation B6)}$$

where: ΔH_j = height difference between two mean geometric heights
β = ballistic coefficient
$\overline{\rho}_x$ = mean atmospheric density for the corresponding mean geometric heights
v_{Tj} = terminal velocity

(vi) An applicant shall estimate the interval debris dispersion (D_j) by multiplying the interval fall time by the algebraic maximum mean wind speed (W_{max}) as shown in equation B7.

$$D_j = t_j \cdot W_{max} \qquad \text{(Equation B7)}$$

(5) Once the D_j are estimated for each height interval, an applicant shall determine the total debris dispersion (D_i) for each Z_i using a linear interpolation and summation exercise, as shown below in equation B8. An applicant shall use a launch point height of zero equal to the surface level of the nearest GGUAS grid location.

$$D_i = D_j \cdot \left(\frac{Z_i - \overline{H}_i}{\overline{H}_{j+1} - \overline{H}_i} \right) + \sum_{n=1}^{j-1} D_n \qquad \text{(Equation B8)}$$

where: n = number of height intervals below j^{th} height interval

(6) Once all the D_i radii have been calculated, an applicant shall produce a launch area flight corridor in accordance with the requirements of subparagraphs (c)(6)(i)-(iv).

(i) On a map meeting the requirements of appendix A, paragraph (b), an applicant shall plot the X_i position location on the flight azimuth for the corresponding Z_i position;

(ii) An applicant shall draw a circle of radius D_i centered on the corresponding X_i position; and

(iii) An applicant shall repeat the instructions in subparagraphs (c)(6)(i)-(ii) for each D_i radius.

(iv) The launch area of a flight corridor is the enveloping line that encloses the outer boundary of the D_i circles as shown in Fig. B-1. The uprange portion of a flight corridor is described by a semi-circle arc that is a portion of either the most uprange D_i dispersion circle, or the overflight exclusion zone (defined by subparagraph (c)(7)), whichever is further uprange.

(7) An applicant shall define an overflight exclusion zone in the launch area in accordance with the requirements of appendix A, subparagraph (c)(2).

(8) An applicant shall draw the launch area flight corridor and overflight exclusion zone on a map or maps that meet the requirements of table B-1.

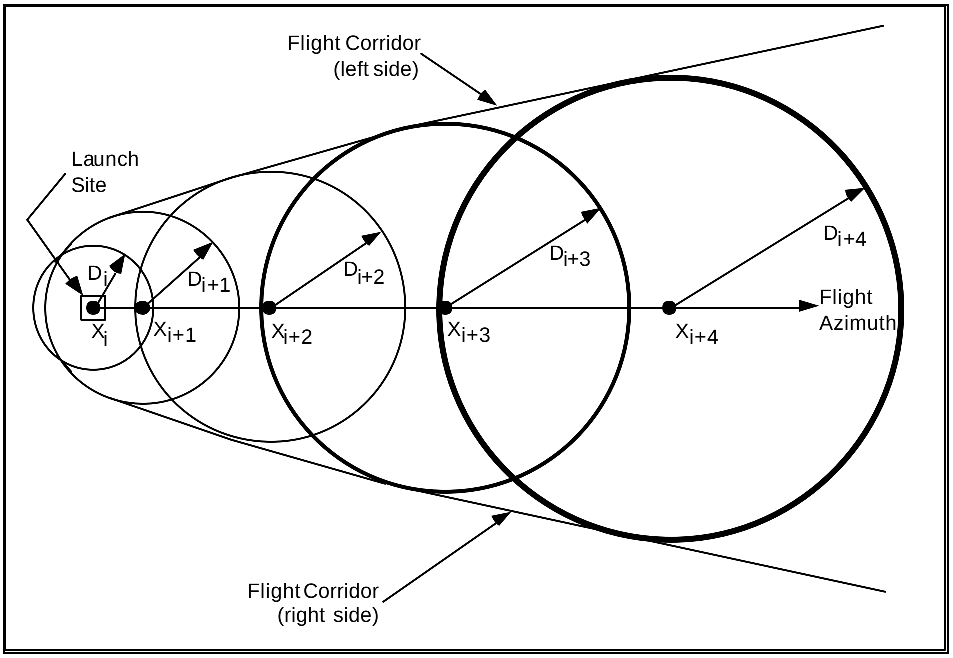

Figure B - 1: Launch Area of a Flight Corridor

(d) Construction of a downrange area of a flight corridor

(1) The downrange area analysis estimates the debris dispersion for the downrange time points on a launch vehicle trajectory. An applicant shall perform the downrange area analysis using the processes and equations of this paragraph.

(2) The downrange area analysis shall include trajectory positions at a height (the Z_i-values) greater than 50,000 feet and nominal trajectory IIP values less than or equal to 5,000 nm. For a guided suborbital launch vehicle, the final IIP value for which an applicant must account is the launch vehicle final stage impact point. Each trajectory time shall be one second or less and is denoted by the subscript “i”.

(3) An applicant shall compute the downrange area of a flight corridor boundary in four steps, from each trajectory time increment: determine a reduction ratio factor; calculate the launch vehicle position after simulating a malfunction turn; rotate the state vector after the malfunction turn in the range of three degrees to one degree as a function of X_i distance downrange; and compute the IIP of the resulting trajectory. The locus of IIPs describes the boundary of the downrange area of a flight corridor. An applicant shall use the following subparagraphs, (d)(3)(i)-(v), to compute the downrange area of the flight corridor boundary:

(i) Compute the downrange distance to the final IIP position for a nominal trajectory as follows:

(A) Using equations B30 through B69, determine the IIP coordinates (ϕ_{max}, λ_{max}) for the nominal state vector before the launch vehicle enters orbit where α in equation B30 is the nominal flight azimuth angle measured from True North.

(B) Using the range and bearing equations of appendix A, paragraph (b)(3), determine the distance (S_{max}) from the launch point coordinates (ϕ_{lp}, λ_{lp}) to the IIP coordinates (ϕ_{max}, λ_{max}) computed in accordance with (3)(i)(A) of this paragraph.

(C) The distance for S_{max} may not exceed 5000 nm. In cases when the actual value exceeds 5000 nm the applicant shall use 5000 nm for S_{max}.

(ii) Compute the reduction ratio factor (F_{ri}) for each trajectory time increment as follows:

(A) Using equations B30 through B69, determine the IIP coordinates (ϕ_i, λ_i) for the nominal state vector where α in equation B30 is the nominal flight azimuth angle measured from True North.

(B) Using the range and bearing equations of appendix A, paragraph (b)(3), determine the distance (S_i) from the launch point coordinates (ϕ_{lp}, λ_{lp}) to the IIP coordinates (ϕ_i, λ_i) computed in (3)(ii)(A) of this paragraph.

(C) The reduction ratio factor is:

$$F_{ri} = \left(1 - \frac{S_i}{S_{max}}\right) \qquad \text{(Equation B9)}$$

(iii) An applicant shall compute the launch vehicle position and velocity components after a simulated malfunction turn for each X_i using the following method.

(A) Turn duration (Δt) = 4 sec.

(B) Turn angle (θ)

$$\theta = (F_{ri}) * 45 \text{ degrees.} \qquad \text{(Equation B10)}$$

The turn angle equations perform a turn in the launch vehicle's yaw plane, as depicted in figure B-2.

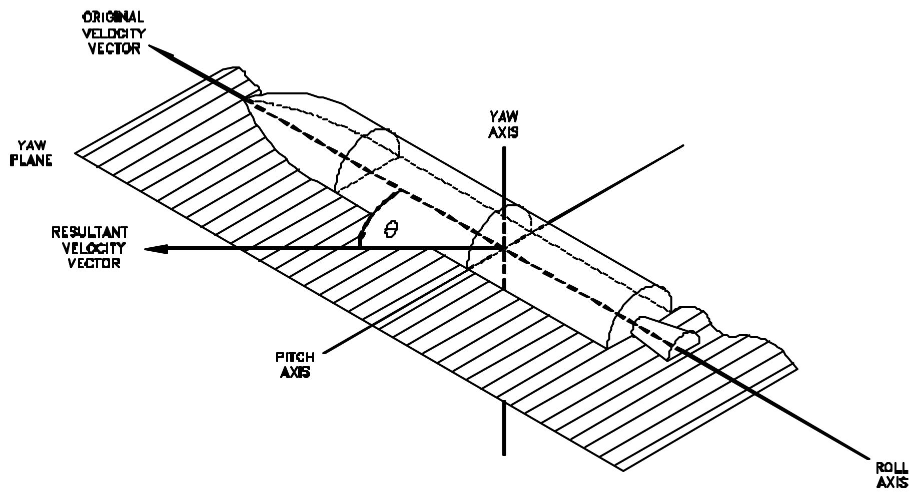

Figure B-2: Velocity Vector Turn Angle in Yaw Plane

(C) Launch vehicle velocity magnitude at the beginning of the turn (V_b) and velocity magnitude at the end of the turn (V_e)

$$V_b = \left(\dot{X}_i^2 + \dot{Y}_i^2 + \dot{Z}_i^2\right)^{0.5} \text{ ft/sec} \qquad \text{(Equation B11)}$$

$$V_e = \left(\dot{X}_{i+5}^2 + \dot{Y}_{i+5}^2 + \dot{Z}_{i+5}^2\right)^{0.5} \text{ ft/sec} \qquad \text{(Equation B12)}$$

(D) Average velocity magnitude over the turn duration ($\overline{V}$)

$$\overline{V_i} = \frac{(V_b + V_e)}{2} \text{ ft/sec} \qquad \text{(Equation B13)}$$

(E) Velocity vector path angle (γ_i) at turn epoch

$$g_i = \tan^{-1}\left[\frac{\dot{Z}_i}{\left(\dot{X}_i^2 + \dot{Y}_i^2\right)^{0.5}}\right] \qquad \text{(Equation B14)}$$

(F) Launch vehicle position components at the end of turn duration

$$X_{90L} = X_i + \overline{V}_i \cdot \Delta t \cdot \cos\left(\frac{-\theta}{2}\right) \cdot \cos(\gamma_i)$$

$$X_{90R} = X_i + \overline{V}_i \cdot \Delta t \cdot \cos\left(\frac{\theta}{2}\right) \cdot \cos(\gamma_i)$$

$$Y_{90L} = Y_i + \overline{V}_i \cdot \Delta t \cdot \sin\left(\frac{-\theta}{2}\right)$$

$$Y_{90R} = Y_i + \overline{V}_i \cdot \Delta t \cdot \sin\left(\frac{\theta}{2}\right)$$

(Equations B15 – B20)

$$Z_{90L} = Z_i + \overline{V}_i \cdot \Delta t \cdot \cos\left(\frac{-\theta}{2}\right) \cdot \sin(\gamma_i) - \left(\frac{1}{2}\right) \cdot g_1 \cdot \Delta t^2$$

$$Z_{90R} = Z_i + \overline{V}_i \cdot \Delta t \cdot \cos\left(\frac{\theta}{2}\right) \cdot \sin(\gamma_i) - \left(\frac{1}{2}\right) \cdot g_1 \cdot \Delta t^2$$

where: $g_1 = 32.17405 \ \mathrm{ft} / \sec^2$

(G) Launch vehicle velocity components at the end of turn duration

$$\dot{X}_{90L} = (X_{90L} - X_i) / \Delta t$$
$$\dot{X}_{90R} = (X_{90R} - X_i) / \Delta t$$
$$\dot{Y}_{90L} = \left|(Y_{90L} - Y_i) / \Delta t\right|$$
$$\dot{Y}_{90R} = (-1) \cdot \left|(Y_{90R} - Y_i) / \Delta t\right|$$
$$\dot{Z}_{90L} = (Z_{90L} - Z_i) / \Delta t$$
$$\dot{Z}_{90R} = (Z_{90R} - Z_i) / \Delta t$$

(Equations B21 – B26)

(iv) An applicant shall rotate the trajectory state vector at the end of the turn duration to the right and left to define the right-lateral flight corridor boundary and the left-lateral flight corridor boundary, respectively. An applicant shall perform the trajectory rotation in conjunction with a trajectory transformation from the $X_{90}, Y_{90}, Z_{90}, \dot{X}_{90}, \dot{Y}_{90}, \dot{Z}_{90}$ components to $E, N, U, \dot{E}, \dot{N}, \dot{U}$. The trajectory subscripts "R" and "L" from equations B15 through B26 have been discarded to reduce the number of equations. An applicant shall transform from $E, N, U, \dot{E}, \dot{N}, \dot{U}$ to $E, F, G, \dot{E}, \dot{F}, \dot{G}$. An applicant shall use the equations of paragraph (d)(3)(iv)(A)-(F) to produce the EFG components necessary to estimate each instantaneous impact point.

(A) An applicant must calculate the flight angle (a)

$$\Delta\alpha_i = 3 - 2 \cdot f_1 \cdot (1 - F_{ri})$$

(Equation B27)

$\alpha_{Li} = (\text{Flight Azimuth} - \Delta\alpha_i)$
for left lateral boundary computations (Equation B28)

- OR

$\alpha_{Ri} = (\text{Flight Azimuth} + \Delta\alpha_i)$
for right lateral boundary computations (Equation B29)

where: $f_1 = \begin{Bmatrix} 0.0: & F_{ri} \geq 0.8 \\ 1.0: & F_{ri} < 0.8 \end{Bmatrix}$

(B) An applicant shall transform X_{90}, Y_{90}, Z_{90} to E,N,U

$$\begin{aligned} E &= X_{90} \sin(a) - Y_{90} \cos(a) \\ N &= X_{90} \cos(a) + Y_{90} \sin(a) \\ U &= Z_{90} \end{aligned}$$

(Equation B30 - B32)

(C) An applicant shall transform $\dot{X}_{90}, \dot{Y}_{90}, \dot{Z}_{90}$ to $\dot{E}, \dot{N}, \dot{U}$.

$$\begin{aligned} \dot{E} &= \dot{X}_{90} \sin(a) - \dot{Y}_{90} \cos(a) \\ \dot{N} &= \dot{X}_{90} \cos(a) + \dot{Y}_{90} \sin(a) \\ \dot{U} &= \dot{Z}_{90} \end{aligned}$$

(Equation B33 - B35)

(D) An applicant shall transform the launch point coordinates (ϕ_0, λ_0 ,h_0) to E_0,F_0,G_0

$$R = a_E \left\{1 - e^2 \left[\sin^2(f_0)\right]\right\}^{-0.5}$$

where: a_E = 20925646.3255 ft
e^2 = 0.00669437999013

(Equation B36 - B39)

$$\begin{aligned} E_0 &= (R + h_0)\cos(f_0)\cos(l_0) \\ F_0 &= (R + h_0)\cos(f_0)\sin(l_0) \\ G_0 &= \left[R(1 - e^2) + h_0\right]\sin(f_0) \end{aligned}$$

(E) An applicant shall transform E,N,U to E_{90},F_{90},G_{90}

$$E_{90} = E\cos(270 - l_0) + N\cos(90 - f_0)\sin(270 - l_0) - U\sin(90 - f_0)\sin(270 - l_0) + E_0$$
$$F_{90} = E\sin(270 - l_0) + N\cos(90 - f_0)\cos(270 - l_0) - U\sin(90 - f_0)\cos(270 - l_0) + F_0$$
$$G_{90} = N\sin(90 - f_0) + U\cos(90 - f_0) + G_0$$

(Equation B40 - B42)

(F) An applicant shall transform $\dot{E}, \dot{N}, \dot{U}$ to $\dot{E}, \dot{F}, \dot{G}$

$$\dot{E}_{90} = \dot{E}\cos(270 - l_0) + \dot{N}\cos(90 - f_0)\sin(270 - l_0) - \dot{U}\sin(90 - f_0)\sin(270 - l_0)$$
$$\dot{F}_{90} = \dot{E}\sin(270 - l_0) + \dot{N}\cos(90 - f_0)\cos(270 - l_0) - \dot{U}\sin(90 - f_0)\cos(270 - l_0)$$
$$\dot{G}_{90} = \dot{N}\sin(90 - f_0) + \dot{U}\cos(90 - f_0)$$

(Equation B43 - B45)

(v) The IIP computation implements an iterative solution to the impact point problem. An applicant shall solve equations B46 through B69, with the appropriate substitutions, up to a maximum of five times. Each repetition of the equations provides a more accurate prediction of the IIP. An applicant shall use the required IIP computations of paragraphs (d)(3)(v)(A)-(W) below. An applicant shall use this IIP computation for both the left- and right-lateral offsets. The IIP computations will result in latitude and longitude pairs for the left-lateral flight corridor boundary and the right-lateral flight corridor boundary. An applicant shall use the lines connecting the latitude and longitude pairs to describe the entire downrange area boundary of the flight corridor up to 5000 nm or a final stage impact dispersion area.

(A) An applicant shall approximate the radial distance ($r_{k,1}$) from the geocenter to the IIP. The distance from the center of the Earth ellipsoid to the launch point shall be used for the initial approximation of $r_{k,1}$ as shown in equation B46.

$$r_{k,1} = \left(E_0^2 + F_0^2 + G_0^2\right)^{0.5}$$ (Equation B46)

(B) An applicant shall compute the radial distance (r) from the geocenter to the launch vehicle position.

$$r = \left(E_{90}^2 + F_{90}^2 + G_{90}^2\right)^{0.5}$$ (Equation B47)

If $r < r_{k,1}$ then the launch vehicle position is below the Earth's surface and an impact point cannot be computed. An applicant must restart the calculations with the next trajectory state vector.

(C) An applicant shall compute the inertial velocity components.

$$\dot{E}I_{90} = \dot{E}_{90} - \omega \cdot F_{90}$$
$$\dot{F}I_{90} = \dot{F}_{90} + \omega \cdot E_{90} \qquad \text{(Equation B48 - B49)}$$

where: $\omega = 4.178074 \text{x} 10^{-3}$ deg/sec

(D) An applicant shall compute the magnitude of the inertial velocity vector.

$$v_0 = \left(\dot{E}I_{90}^2 + \dot{F}I_{90}^2 + \dot{G}_{90}^2\right)^{0.5} \qquad \text{(Equation B50)}$$

(E) An applicant shall compute the eccentricity of the trajectory ellipse multiplied by the cosine of the eccentric anomaly at epoch (ε_c).

$$e_c = \left(\frac{r \cdot v_0^2}{K}\right) - 1 \qquad \text{(Equation B51)}$$

where: $K = 1.407644 \text{x} 10^{16}\ \text{ft}^3/\text{sec}^2$

(F) An applicant shall compute the semi-major axis of the trajectory ellipse (a_t).

$$a_t = \frac{r}{(1 - e_c)} \qquad \text{(Equation B52)}$$

If $a_t < 0$ or $a_t > \infty$ then the trajectory orbit is not elliptical, but is hyperbolic or parabolic, and an impact point cannot be computed. The launch vehicle has achieved escape velocity and the applicant may terminate computations.

(G) An applicant shall compute the eccentricity of the trajectory ellipse multiplied by the sine of the eccentric anomaly at epoch (ε_s).

$$e_s = \frac{\left(E_{90}\dot{E}I_{90} + F_{90}\dot{F}I_{90} + G_{90}\dot{G}_{90}\right)}{\left(K \cdot a_t\right)^{0.5}} \qquad \text{(Equation B53)}$$

(H) An applicant shall compute the eccentricity of the trajectory ellipse squared $\left(e^2\right)$.

$$e^2 = \left(e_c^2 + e_s^2\right) \qquad \text{(Equation B54)}$$

If $[a_t(1-e)-a_E]>0$ and $\varepsilon \geq 0$ then the trajectory perigee height is positive and an impact point cannot be computed. The launch vehicle has achieved Earth orbit and the applicant may terminate computations.

(I) An applicant shall compute the eccentricity of the trajectory ellipse multiplied by the cosine of the eccentric anomaly at impact (ε_{c_k}).

$$e_{c_k} = \frac{\left(a_t - r_{k,1}\right)}{a_t} \qquad \text{(Equation B55)}$$

(J) An applicant shall compute the eccentricity of the trajectory ellipse multiplied by the sine of the eccentric anomaly at impact (ε_{s_k}).

$$e_{s_k} = -\left(e^2 - e_{c_k}^2\right)^{0.5} \qquad \text{(Equation B56)}$$

If $\varepsilon_{s_k} < 0$ then the trajectory orbit does not intersect the Earth's surface and an impact point cannot be computed. The launch vehicle has achieved Earth orbit and the applicant may terminate computations.

(K) An applicant shall compute the cosine of the difference between the eccentric anomaly at impact and the eccentric anomaly at epoch ($\Delta\varepsilon_{c_k}$).

$$\Delta e_{c_k} = \frac{\left(e_{c_k} \cdot e_c\right) + \left(e_{s_k} \cdot e_s\right)}{e^2} \qquad \text{(Equation B57)}$$

(L) An applicant shall compute the sine of the difference between the eccentric anomaly at impact and the eccentric anomaly at epoch ($\Delta\varepsilon_{s_k}$).

$$\Delta e_{s_k} = \frac{\left(e_{s_k} \cdot e_c\right) - \left(e_{c_k} \cdot e_s\right)}{e^2} \qquad \text{(Equation B58)}$$

(M) An applicant shall compute the f-series expansion of Kepler's equations.

$$f_2 = \frac{\left(\Delta e_{c_k} - e_c\right)}{\left(1 - e_c\right)} \qquad \text{(Equation B59)}$$

(N) An applicant shall compute the g-series expansion of Kepler's equations.

$$g_2 = \left(\Delta e_{s_k} + e_s - e_{s_k}\right)\left(\frac{a_t^3}{K}\right)^{0.5} \qquad \text{(Equation B60)}$$

(O) An applicant shall compute the E,F,G coordinates at impact (E_i,F_i,G_i).

$$\begin{aligned} E_k &= f_2 \cdot E_{90} + g_2 \cdot \dot{E}I_{90} \\ F_k &= f_2 \cdot F_{90} + g_2 \cdot \dot{F}I_{90} \\ G_k &= f_2 \cdot G_{90} + g_2 \cdot \dot{G}_{90} \end{aligned} \qquad \text{(Equation B61 - B63)}$$

(P) An applicant shall approximate the distance from the geocenter to the launch vehicle position at impact ($r_{k,2}$).

$$r_{k,2} = \frac{a_E}{\left[\left(\frac{e^2}{1-e^2}\right)\left(\frac{G_k}{r_{k,1}}\right)^2 + 1\right]^{0.5}} \qquad \text{(Equation B64)}$$

where: $a_E = 20925646.3255$ ft

$e^2 = 0.00669437999013$

(Q) An applicant shall let $r_{k+1,1} = r_{k,2}$, substitute $r_{k+1,1}$ for $r_{k,1}$ in equation B55 and repeat equations B55 - B64 up to four more times increasing "k" by an increment of one on each loop (e.g. $k \in \{1, 2, 3, 4, 5\}$). If $\left|r_{5,1} - r_{5,2}\right| > 1$ then the iterative solution does not converge and an impact point does not meet the accuracy tolerance of plus or minus one foot. An applicant must try more iterations, or restart the calculations with the next trajectory state vector.

(R) An applicant shall compute the difference between the eccentric anomaly at impact and the eccentric anomaly at epoch ($\Delta\varepsilon$).

$$\Delta e = \tan^{-1}\left(\frac{\Delta e_{s_5}}{\Delta e_{c_5}}\right) \qquad \text{(Equation B65)}$$

(S) An applicant shall compute the time of flight from epoch to impact (t).

$$t = \left(\Delta e + e_s - e_{s_5}\right)\left(\frac{a_t^3}{K}\right)^{0.5} \qquad \text{(Equation B66)}$$

(T) An applicant shall compute the geocentric latitude at impact (ϕ').

$$f_i' = \sin^{-1}\left(\frac{G_5}{r_{5,2}}\right) \qquad \text{(Equation B67)}$$

$$\text{where: } +90^\circ \geq f_i' \geq -90^\circ$$

(U) An applicant shall compute the geodetic latitude at impact (ϕ).

$$f_i = \tan^{-1}\left[\frac{\tan\left(f_i'\right)}{\left(1 - e^2\right)}\right] \qquad \text{(Equation B68)}$$

$$\text{where: } +90^\circ \geq f_i \geq -90^\circ$$

(V) An applicant shall compute the East longitude at impact (λ).

$$l_i = \tan^{-1}\left(\frac{F_5}{E_5}\right) - wt \qquad \text{(Equation B69)}$$

(W) If the range from the launch point to the impact point is equal to or greater than 5000 nm, an applicant shall terminate IIP computations.

(4) For a guided suborbital launch vehicle, an applicant shall define a final stage impact dispersion area as part of the flight corridor and show the area on a map using the following procedure:

(i) For equation B70 below, an applicant shall use an apogee altitude (H_{ap}) corresponding to the highest altitude reached by the launch vehicle final stage in the applicant's launch vehicle trajectory analysis done in accordance with paragraph (b)(1)(ii).

(ii) An applicant shall define the final stage impact dispersion area by using a dispersion factor [DISP(H_{ap})] as shown below. An applicant shall calculate the impact dispersion radius (R) for the final launch vehicle stage. An applicant shall set R equal to the maximum apogee altitude (H_{ap}) multiplied by the dispersion factor as shown below:

$$R = H_{ap} \cdot DISP(H_{ap}) \qquad \text{(Equation B70)}$$

where: $DISP(H_{ap}) = 0.05$

(5) An applicant shall combine the launch area and downrange area flight corridor and any final stage impact dispersion area for a guided suborbital launch vehicle.

(i) On the same map with the launch area flight corridor, an applicant shall plot the latitude and longitude positions of the left and right sides of the downrange area of the flight corridor calculated in accordance with subparagraph (d)(3).

(ii) An applicant shall connect the latitude and longitude positions of the left side of the downrange area of the flight corridor sequentially starting with the last IIP calculated on the left side and ending with the first IIP calculated on the left side. An applicant shall repeat this procedure for the right side.

(iii) An applicant shall connect the left sides of the launch area and downrange portions of the flight corridor. An applicant shall repeat this procedure for the right side.

(iv) An applicant shall plot the overflight exclusion zone defined in subparagraph (c)(7).

(v) An applicant shall draw any impact dispersion area on the downrange map with the center of the impact dispersion area on the launch vehicle final stage impact point obtained from the applicant's launch vehicle trajectory analysis done in accordance with subparagraph (b)(1)(ii).

(e) Evaluate the launch site

(1) An applicant shall evaluate the flight corridor for the presence of populated areas. If no populated area is located within the flight corridor, then no additional steps are necessary.

(2) If a populated area is located in an overflight exclusion zone, an applicant may modify its proposal or demonstrate that there are times when no people are present or that the applicant has an agreement in place to evacuate the public from the overflight exclusion zone during a launch.

(3) If a populated area is located within the flight corridor, an applicant may modify its proposal or complete an overflight risk analysis in accordance with appendix C.

Appendix C to Part 420
Risk Analysis

(a) Introduction

(1) This appendix provides a method for an applicant to estimate the expected casualty (E_c) for a launch of a guided expendable launch vehicle using a flight corridor generated either by appendix A or appendix B. This appendix also provides an applicant options to simplify the method where population at risk is minimal.

(2) An applicant shall perform a risk analysis when a populated area is located within a flight corridor defined by either appendix A or appendix B. If the estimated expected casualty exceeds $30x10^{-6}$, an applicant may either modify its proposal, or if the flight corridor used was generated by the appendix A method, use the appendix B method to narrow the flight corridor and then redo the overflight risk analysis pursuant to this appendix. If the estimated expected casualty still exceeds $30x10^{-6}$, the FAA will not approve the location of the proposed launch point.

(b) Data Requirements

(1) An applicant shall obtain the data specified by subparagraphs (b)(2) and (3) and summarized in table C-1. Table C-1 provides sources where an applicant may obtain data acceptable to the FAA. An applicant must also employ the flight corridor information from appendix A or B, including flight azimuth and, for an appendix B flight corridor, trajectory information.

(2) Population data. Total population (N) and the total landmass area within a populated area (A) are required. Population data up to and including 100 nm from the launch point are required at the U.S. census block group level. Population data downrange from 100 nm are required at no greater than 1^o x 1^o latitude/longitude grid coordinates.

(3) Launch vehicle data. Launch vehicle data consist of the launch vehicle failure probability (P_f), the launch vehicle effective casualty area (A_c), trajectory position data, and the overflight dwell time (t_d). The failure probability is a constant (P_f = 0.10) for a guided orbital or suborbital expendable launch vehicle. Table C-3 provides effective casualty area data based on IIP range. Trajectory position information is provided from distance computations provided by this appendix for an appendix A flight corridor, or trajectory data used in appendix B for an appendix B flight corridor. The dwell time (t_d) may be determined from trajectory data produced when creating an appendix B flight corridor.

Table C-1. Overflight Analysis Data Requirements

Data Category	Data Item	Data Source
Population Data	Total population within a populated area (N)	Within 100 nm of the launch point: U.S. census data at the census block-group level. Downrange from 100 nm beyond the launch point, world population data are available from:
	Total landmass area within the populated area (A)	Carbon Dioxide Information Analysis Center (CDIAC) Oak Ridge National Laboratory Database - Global Population Distribution (1990), Terrestrial Area and Country Name Information on a One by One Degree Grid Cell Basis (DB1016 (8-1996)
Launch Vehicle Data	Failure probability - $P_f = 0.10$	N/A
	Effective casualty area (A_c)	See table C-3
	Overflight dwell time	Determined by range from the launch point or trajectory used by applicant
	Nominal trajectory data (for an appendix B flight corridor only)	See appendix B, table B-1.

(c) Estimating corridor casualty expectation

(1) A corridor casualty expectation [E_c(Corridor)] estimate is the sum of the expected casualty measurement of each populated area inside a flight corridor.

(2) An applicant shall identify and locate each populated area in the proposed flight corridor.

(3) An applicant shall determine the probability of impact in each populated area using the procedures in subparagraphs (5) or (6) of this paragraph. Figures C-1 and C-2 illustrate an area considered for probability of impact (P_i) computations by the dashed-lined box around the populated area within a flight corridor, and figure C-3 illustrates a populated area in a final stage impact dispersion area. An applicant shall then estimate the E_c for each populated area in accordance with subparagraphs (7) and (8) of this paragraph.

(4) The P_i computations do not directly account for populated areas whose areas are bisected by an appendix A flight corridor centerline or an appendix B nominal trajectory ground trace. Accordingly, an applicant must evaluate P_i for each of the bi-sections as two separate populated areas, as shown in figure C-4, which shows one bi-section to the left of an appendix A flight corridor's centerline and one to its right.

(5) Probability of impact (P_i) computations for a populated area in an appendix A flight corridor. An applicant shall compute P_i for each populated area using the following method:

(i) For the launch and downrange areas, but not for a final stage impact dispersion area for a guided suborbital launch vehicle, an applicant shall compute P_i for each populated area using the following equation:

$$P_i = \frac{\left(\frac{|y_2 - y_1|}{s_y}\right)}{6\sqrt{2p}} \cdot \left(\exp\left(\frac{-\left(y_1/s_y\right)^2}{2}\right) + 4 \cdot \exp\left[\frac{-\left(\frac{y_1 + y_2}{2s_y}\right)^2}{2}\right] + \exp\left(\frac{-\left(y_2/s_y\right)^2}{2}\right) \right) \cdot \left[\frac{P_f}{C} \cdot \frac{(x_2 - x_1)}{\dot{R}}\right]$$

(Equation C1)

where:

x_1, x_2 = closest and farthest downrange distance (nm) along the flight corridor centerline to the populated area (see figure C-1)

y_1, y_2 = closest and farthest cross range distance (nm) to the populated area measured from the flight corridor centerline (see figure C-1)

s_y = one-third of the cross range distance from the centerline to the flight corridor boundary (see figure C-1)

exp = exponential function (e^x)

P_f = probability of failure = 0.10

$\dot{R}$ = IIP range rate (nm/sec) (see table C-2)

C = 643 seconds (constant)

Table C-2: IIP Range Rate vs. IIP Range

IIP Range (nm)	IIP Range Rate (nm/s)
0 - 75	0.75
76 - 300	1.73
301 - 900	4.25
901 - 1700	8.85
1701 - 2600	19.75

2601 - 3500	42.45
3501 - 4500	84.85
4501 - 5250	154.95

(ii) For each populated area within a final stage impact dispersion area, an applicant shall compute P_i using the following method:

(A) An applicant shall estimate the probability of final stage impact in the x and y sectors of each populated area within the final stage impact dispersion area using equations C2 and C3:

$$P_x = \frac{\left(\frac{|x_2 - x_1|}{\sigma_x}\right)}{6\sqrt{2\pi}} \cdot \left(\exp\left(\frac{-\left(x_1 / \sigma_x \right)^2}{2} \right) + 4 \cdot \exp\left[\frac{-\left(\frac{x_1 + x_2}{2\sigma_x} \right)^2}{2} \right] + \exp\left(\frac{-\left(x_2 / \sigma_x \right)^2}{2} \right) \right)$$

(Equation C2)

where: x_1, x_2 = closest and farthest downrange distance, measured along the flight corridor centerline, measured from the nominal impact point to the populated area (see figure C-3)

σ_x = one-third of the impact dispersion radius (see figure C-3)

exp = exponential function (e^x)

$$P_y = \frac{\left(\frac{|y_2 - y_1|}{\sigma_y}\right)}{6\sqrt{2\pi}} \cdot \left(\exp\left(\frac{-\left(y_1 / \sigma_y \right)^2}{2} \right) + 4 \cdot \exp\left[\frac{-\left(\frac{y_1 + y_2}{2\sigma_y} \right)^2}{2} \right] + \exp\left(\frac{-\left(y_2 / \sigma_y \right)^2}{2} \right) \right)$$

(Equation C3)

where: y_1, y_2 = closest and farthest cross range distance to the populated area measured from the flight corridor centerline (see figure C-3)

σ_y = one-third of the impact dispersion radius (see figure C-3) exp = exponential function (e^x)

(B) If a populated area intersects the impact dispersion area boundary so that the x_2 or y_2 distance would otherwise extend outside the impact dispersion area, the x_2 or y_2 distance should be set equal to the impact dispersion area radius. The x_2 distance for populated area A in figure C-3 is an example. If a populated area intersects the flight azimuth, an applicant shall solve equation C3 by obtaining the solution in two parts. An applicant shall determine, first, the probability between $y_1 = 0$ and $y_2 = a$ and, second, the probability between $y_1 = 0$ and $y_2 = b$, as depicted in figure C-4. The probability P_y is then equal to the sum of the probabilities of the two parts. If a populated area intersects the line that is normal to the flight azimuth on the impact point, an applicant shall solve equation C2 by obtaining the solution in two parts in the same manner as with the values of x.

(C) An applicant shall calculate the probability of impact for each populated area using equation C4 below:

$$P_I = P_s \cdot P_x \cdot P_y \qquad \text{(Equation C4)}$$

where: $P_s = 1 - P_f = 0.90$

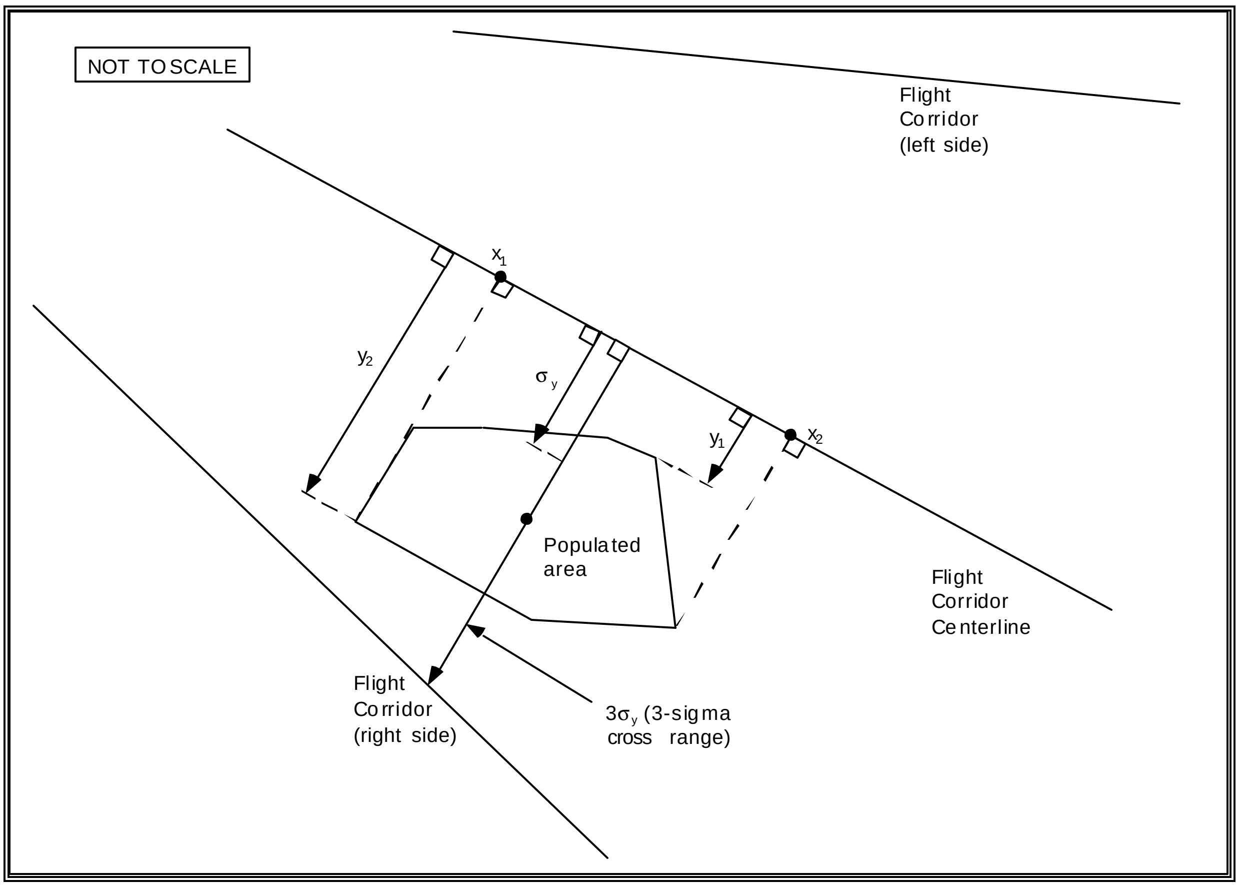

Figure C-1: Analysis of an Appendix A Flight Corridor

(6) Probability of impact computations for a populated area in an appendix B flight corridor. An applicant shall compute P_i using the following method:

(i) For the launch and downrange areas, but not for a final stage impact dispersion area for a guided suborbital launch vehicle, an applicant shall compute P_i for each populated area using the following equation:

$$P_i = \frac{\left(\frac{\left|y_2 - y_1\right|}{s_y}\right)}{6\sqrt{2p}} \cdot \left(\exp\left(\frac{-\left({}^{y_1}\!/\!_{s_y} \right)^2}{2} \right) + 4 \cdot \exp\left[\frac{-\left(\frac{y_1 + y_2}{2s_y} \right)^2}{2} \right] + \exp\left(\frac{-\left({}^{y_2}\!/\!_{s_y} \right)^2}{2} \right) \right) \cdot \left(\frac{P_f}{t} \cdot t_d \right)$$

(Equation C5)

where:

y_1, y_2 = closest and farthest cross range distance (nm) to a populated area measured from the nominal trajectory IIP ground trace (see figure C-2)

s_y = one-third of the cross range distance (nm) from nominal trajectory to the flight corridor boundary (see figure C-2)

exp = exponential function (e^x)

P_f = probability of failure = 0.10

t = flight time from lift-off to orbital insertion (seconds)

t_d = overflight dwell time (seconds)

(ii) For each populated area within a final stage impact dispersion area, an applicant shall compute P_i using the following method:

(A) An applicant shall estimate the probability of final stage impact in the x and y sectors of each populated area within the final stage impact dispersion area using equations C6 and C7:

$$P_x = \frac{\left(\frac{\left|x_2 - x_1\right|}{s_x}\right)}{6\sqrt{2p}} \cdot \left(\exp\left(\frac{-\left({}^{x_1}\!/\!_{s_x} \right)^2}{2} \right) + 4 \cdot \exp\left[\frac{-\left(\frac{x_1 + x_2}{2s_x} \right)^2}{2} \right] + \exp\left(\frac{-\left({}^{x_2}\!/\!_{s_x} \right)^2}{2} \right) \right)$$

(Equation C6)

where: x_1, x_2 = closest and farthest downrange distance, measured along nominal trajectory IIP ground trace, measured from the nominal impact point to the populated area (see figure C-3)

σ_x = one-third of the impact dispersion radius (see figure C-3)

exp = exponential function (e^x)

$$P_y = \frac{\left(\frac{|y_2 - y_1|}{s_y}\right)}{6\sqrt{2p}} \cdot \left(\exp\left(\frac{-\left(y_1 / s_y \right)^2}{2} \right) + 4 \cdot \exp\left[\frac{-\left(\frac{y_1 + y_2}{2 s_y} \right)^2}{2} \right] + \exp\left(\frac{-\left(y_2 / s_y \right)^2}{2} \right) \right)$$

(Equation C7)

where: y_1,y_2 = closest and farthest cross range distance to the populated area measured from the nominal trajectory IIP ground trace (see figure C-3)

σ_y = one-third of the impact dispersion radius (see figure C-3)

exp = exponential function (e^x)

(B) If a populated area intersects the impact dispersion area boundary so that the x_2 or y_2 distance would otherwise extend outside the impact dispersion area, the x_2 or y_2 distance should be set equal to the impact dispersion area radius. The x_2 distance for populated area A in figure C-3 is an example. If a populated area intersects the flight azimuth, an applicant shall solve equation C7 by obtaining the solution in two parts. An applicant shall determine, first, the probability between $y_1 = 0$ and $y_2 = a$ and, second, the probability between $y_1 = 0$ and $y_2 = b$, as depicted in figure C-4. The probability P_y is then equal to the sum of the probabilities of the two parts. If a populated area intersects the line that is normal to the flight azimuth on the impact point, an applicant shall solve equation C6 by obtaining the solution in two parts in a similar manner with the values of x.

(C) An applicant shall calculate the probability of impact for each populated area using equation C8 below:

$$P_I = P_s \cdot P_x \cdot P_y \qquad \text{(Equation C8)}$$

where: $P_s = 1 - P_f = 0.90$

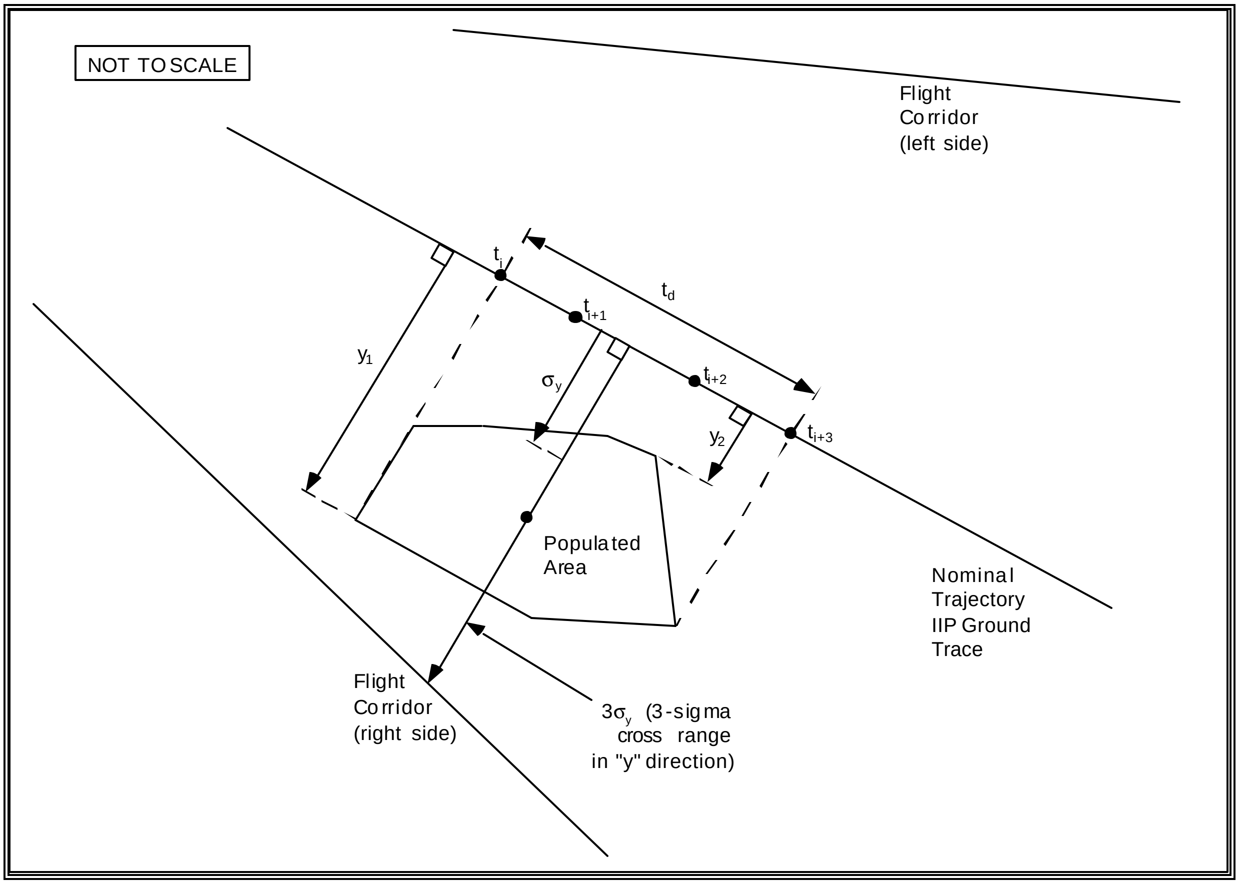

Figure C-2: Analysis of an Appendix B Flight Corridor

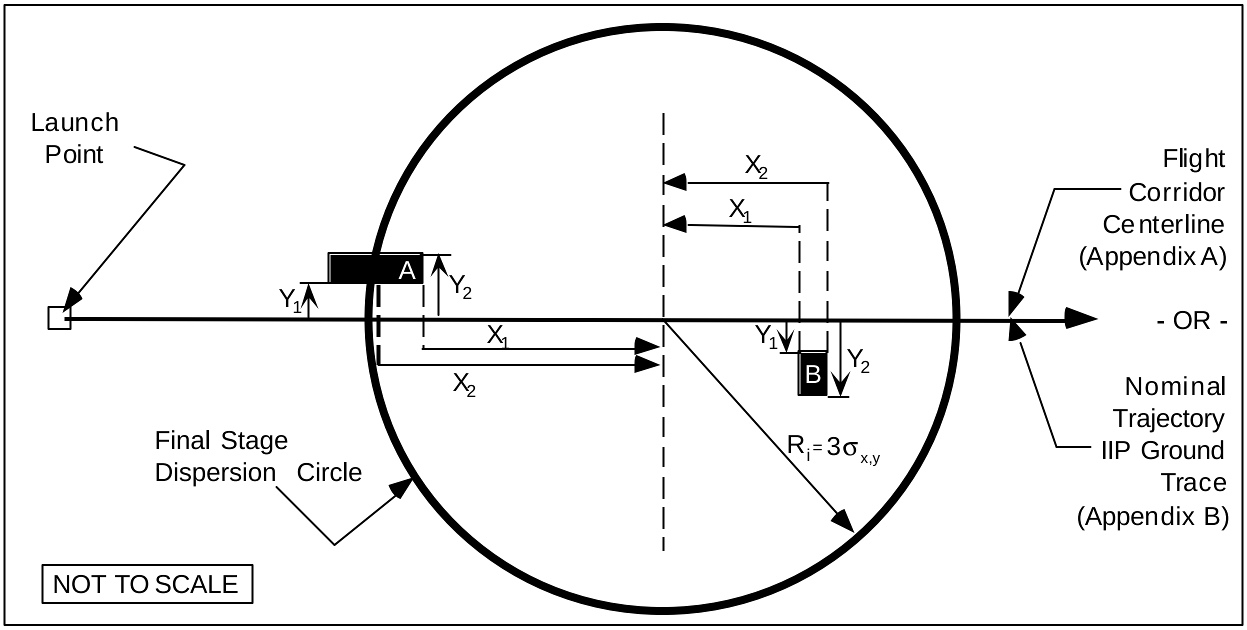

Figure C-3: Appendix A and B Final Stage Impact Risk Analysis

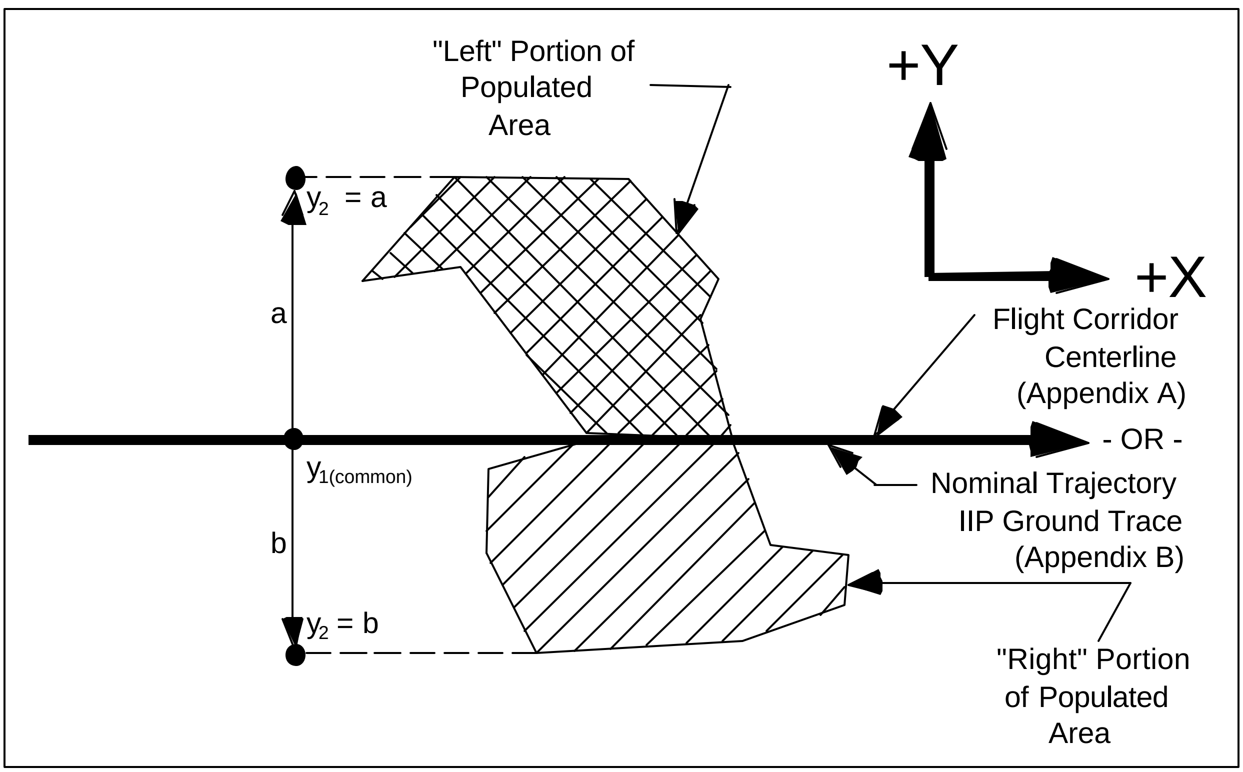

Figure C-4: Flight Azimuth Intersecting a Populated Area

(7) Using the P_i calculated in either subparagraph (c)(5) or (6) of this paragraph, an applicant shall calculate the casualty expectancy for each populated area within the flight corridor in accordance with equation C9. E_{ck} is the casualty expectancy for a given populated area as shown in equation C9, where individual populated areas are designated with the subscript "k".

$$E_{ck} = P_i \cdot \left(\frac{A_c}{A_k} \right) \cdot N_k \qquad \text{(Equation C9)}$$

where: A_c = casualty area (from table C-3)
A_k = populated area
N_k = population in A_k

Table C-3: Effective Casualty Area (miles²) as a function of IIP Range (nm)

Orbital Launch Vehicles					**Suborbital Launch Vehicles**
IIP Range (nmi)	Small	Medium	Medium Large	Large	Guided
0 - 49	0.43	0.53	0.71	1.94	0.43
50 - 1749	0.13	0.0022	0.11	0.62	0.13
1750 - 5000	3.59×10^{-6}	8.3×10^{-4}	1.08×10^{-1}	7.17×10^{-1}	3.59×10^{-6}

(8) An applicant shall estimate the total corridor risk using the following summation of risk:

$$\text{Ec(Corrido r)} = \left(\sum_{k=1}^{n} E_{c_k} \right) \qquad \text{(Equation C10)}$$

(9) Alternative casualty expectancy (E_C) analyses. An applicant may employ specified variations to the analysis defined by subparagraphs (c)(1) - (8). Those variations are identified in subparagraphs (9)(i) through (vi) of this paragraph. Subparagraphs (i) through (iv) permit an applicant to make conservative assumptions that would lead to an overestimation of the corridor E_C compared with the analysis defined by subparagraphs (c)(1) - (8). In subparagraphs (v) and (vi), an applicant that would otherwise fail the analysis prescribed by subparagraphs (c)(1) - (8) may avoid (c)(1) - (8)'s overestimation of the probability of impact in each populated area. An applicant employing a variation shall identify the variation used, show and discuss the specific assumptions made to modify the analysis defined by subparagraphs (c)(1) - (8), and demonstrate how each assumption leads to overestimation of the corridor E_C compared with the analysis defined by subparagraphs (c)(1) - (c)(8).

(i) Assume that P_x and P_y have a value of 1.0 for all populated areas.

(ii) Combine populated areas into one or more larger populated areas, and use a population density for the combined area or areas equal to the most densely populated area.

(iii) For any given populated area, assume P_y has a value of one.

(iv) For any given P_x sector (an area spanning the width of a flight corridor and bounded by two time points on the trajectory IIP ground trace) assume P_y has a value of one and use a population density for the sector equal to the most densely populated area.

(v) For a given populated area, divide the populated area into smaller rectangles, determine P_i for each individual rectangle, and sum the individual impact probabilities to determine P_i for the entire populated area.

(vi) For a given populated area, use the ratio of the populated area to the area of the P_i rectangle from the subparagraph (c)(1) - (8) analysis.

(d) Evaluation of Results

(1) If the estimated expected casualty does not exceed $30x10^{-6}$, the FAA will approve the launch site location.

(2) If the estimated expected casualty exceeds $30x10^{-6}$, then an applicant may either modify its proposal, or, if the flight corridor used was generated by the appendix A method, use the appendix B method to narrow the flight corridor and then perform another appendix C risk analysis.

Appendix D to Part 420
Impact Dispersion Areas and Casualty Expectancy Estimate
for an Unguided Suborbital Launch Vehicle

(a) Introduction

(1) This appendix provides a method for determining the acceptability of the location of a launch point from which an unguided suborbital launch vehicle would be launched. The appendix describes how to define an overflight exclusion zone and impact dispersion areas, and how to evaluate whether the public risk presented by the launch of an unguided suborbital launch vehicle remains at acceptable levels.

(2) An applicant shall base its analysis on an unguided suborbital launch vehicle whose final launch vehicle stage apogee represents the intended use of the launch point.

(3) An applicant shall use the apogee of each stage of an existing unguided suborbital launch vehicle with a final launch vehicle stage apogee equal to the one proposed, and calculate each impact range and dispersion area using the equations provided.

(4) This appendix also provides a method for performing an impact risk analysis that estimates the expected casualty (E_c) within each impact dispersion area. This appendix provides an applicant options to simplify the method where population at risk is minimal.

(5) If the estimated E_c is less than or equal to $30x10^{-6}$, the FAA will approve the launch point for unguided suborbital launch vehicles. If the estimated E_c exceeds $30x10^{-6}$, the proposed launch point will fail the launch site location review.

(b) Data Requirements

(1) An applicant shall employ the apogee of each stage of an existing unguided suborbital launch vehicle whose final stage apogee represents the maximum altitude to be reached by unguided suborbital launch vehicles launched from the launch point. The apogee shall be obtained from one or more actual flights of an unguided suborbital launch vehicle launched at an 84 degree elevation.

(2) An applicant shall satisfy the map and plotting data requirements of appendix A, paragraph (b).

(3) Population data. An applicant shall use total population (N) and the total landmass area within a populated area (A) for all populated areas within an impact dispersion area.. Population data up to and including 100 nm from the launch point are required at the U.S. census block group level. Population data downrange from 100 nm are required at no greater than 1^o x 1^o latitude/longitude grid coordinates.

(c) Overflight Exclusion Zone and Impact Dispersion Areas

(1) An applicant shall choose a flight azimuth from a launch point.

(2) An applicant shall define an overflight exclusion zone as a circle with a radius of 1600 feet centered on the launch point.

(3) An applicant shall define an impact dispersion area for each stage of the suborbital launch vehicle chosen in accordance with subparagraph (b)(1) in accordance with the following:

(i) An applicant shall calculate the impact range for the final launch vehicle stage (D_n). An applicant shall set D_n equal to the last stage apogee altitude (H_n) multiplied by an impact range factor [$IP(H_n)$] in accordance with the following:

$$D_n = H_n \cdot IP(H_n) \qquad \text{(Equation D1)}$$

where: $IP(H_n)$ = 0.4 for an apogee less than 100 km, and
$IP(H_n)$ = 0.7 for an apogee of 100 km or greater.

(ii) An applicant shall calculate the impact range for each intermediate stage (D_i), where $i \in \{1,2,3,\ldots(n-1)\}$, and where n is the total number of launch vehicle stages. Using the apogee altitude (H_i) of each intermediate stage, an applicant shall use equation D1 to compute the impact range of each stage by substituting H_i for H_n. An applicant shall use the impact range factors provided by equation D1.

(iii) An applicant shall calculate the impact dispersion radius for the final launch vehicle stage (R_n). An applicant shall set R_n equal to the last stage apogee altitude (H_n) multiplied by an impact dispersion factor [$DISP(H_n)$] in accordance with the following:

$$R_n = H_n \cdot DISP(H_n) \qquad \text{(Equation D2)}$$

where: $DISP(H_n)$ = 0.4 for an apogee less than 100 km, and
$DISP(H_n)$ = 0.7 for an apogee of 100 km or greater.

(iv) An applicant shall calculate the impact dispersion radius for each intermediate stage (R_i), where $i \in \{1,2,3,...(n-1)\}$, and where n is the total number of launch vehicle stages. Using the apogee altitude (H_i) of each intermediate stage, an applicant shall use equation D2 to compute an impact dispersion radius of each stage by substituting H_i for H_n. An applicant shall use the dispersion factors provided by equation D2.

(4) An applicant shall display an overflight exclusion zone, each intermediate and final stage impact point (D_i through D_n), and each impact dispersion area for the intermediate and final launch vehicle stages on maps in accordance with paragraph (b)(2).

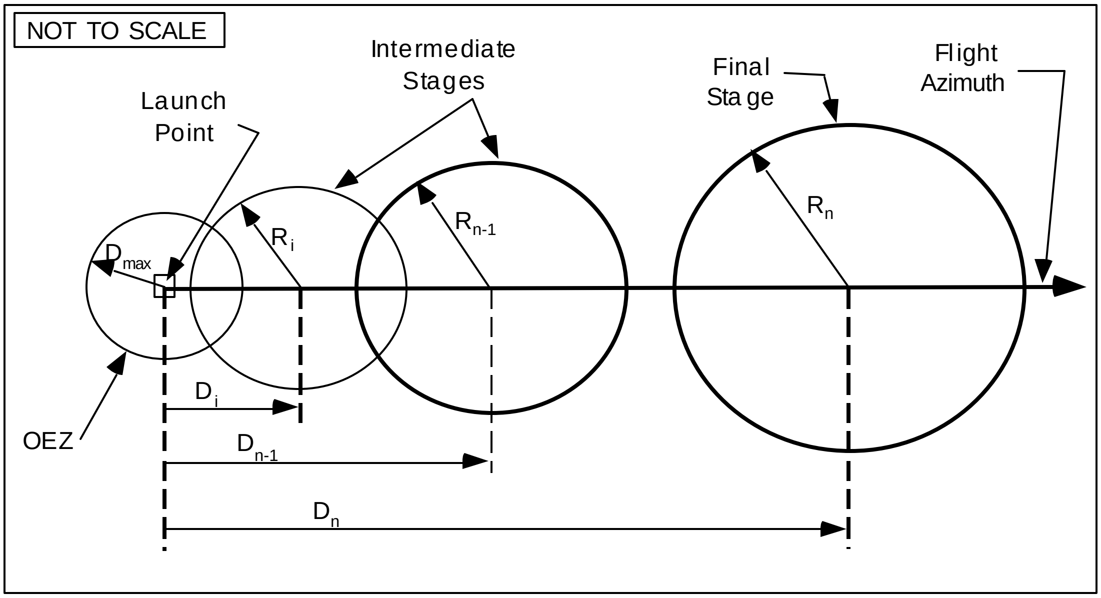

Figure D-1
Unguided Suborbital Launch Vehicle Overflight Exclusion Zone and Impact Dispersion Areas

(d) Evaluate the Overflight Exclusion Zone and Impact Dispersion Areas

(1) An applicant shall evaluate the overflight exclusion zone and each impact dispersion area for the presence of any populated areas. If an applicant determines that no populated area is located within the overflight exclusion zone or any impact dispersion area, then no additional steps are necessary.

(2) If a populated area is located in an overflight exclusion zone, an applicant may modify its proposal or demonstrate that there are times when no people are present or that the applicant has an agreement in place to evacuate the public from the overflight exclusion zone during a launch.

(3) If a populated area is located within any impact dispersion area, an applicant may modify its proposal and define a new overflight exclusion zone and new impact dispersion areas, or perform an impact risk analysis in accordance with paragraph (e).

(e) Impact Risk Analysis

(1) An applicant shall estimate the expected average number of casualties, E_C, within the impact dispersion areas according to the following method:

(i) An applicant shall calculate the E_C by summing the impact risk for the impact dispersion areas of the final launch vehicle stage and all intermediate stages. An applicant shall estimate E_c for the impact dispersion area of each stage by using equations D3 through D7 for each of the populated areas located within the impact dispersion areas.

(ii) An applicant shall estimate the probability of impacting inside the X and Y sectors of each populated area within each impact dispersion area using equations D3 and D4:

$$P_x = \frac{\left(\frac{x_2}{\sigma_x} - \frac{x_1}{\sigma_x}\right)}{6\sqrt{2\pi}} \cdot \left(\exp\left(\frac{-\left(\frac{x_1}{\sigma_x}\right)^2}{2}\right) + 4 \cdot \exp\left[\frac{-\left(\frac{(x_1 + x_2)}{2\sigma_x}\right)^2}{2}\right] + \exp\left(\frac{-\left(\frac{x_2}{\sigma_x}\right)^2}{2}\right)\right)$$

(Equation D3)

where: x_1, x_2 = closest and farthest downrange distance to populated area (see figure D-2)

σ_x = one-third of the impact dispersion radius (see figure D-2)

exp = exponential function (e^x)

$$P_y = \frac{\left(\frac{|y_2|}{\sigma_y} - \frac{|y_1|}{\sigma_y}\right)}{6\sqrt{2\pi}} \cdot \left(\exp\left(\frac{-\left(y_1/\sigma_y\right)^2}{2}\right) + 4 \cdot \exp\left[-\frac{\left(\frac{y_1 + y_2}{2\sigma_y}\right)^2}{2}\right] + \exp\left(\frac{-\left(y_2/\sigma_y\right)^2}{2}\right)\right)$$

(Equation D4)

where: y_1, y_2 = closest and farthest cross range distance to the populated area (see figure D-2)

σ_y = one-third of the impact dispersion radius (see figure D-2)

exp = exponential function (e^x)

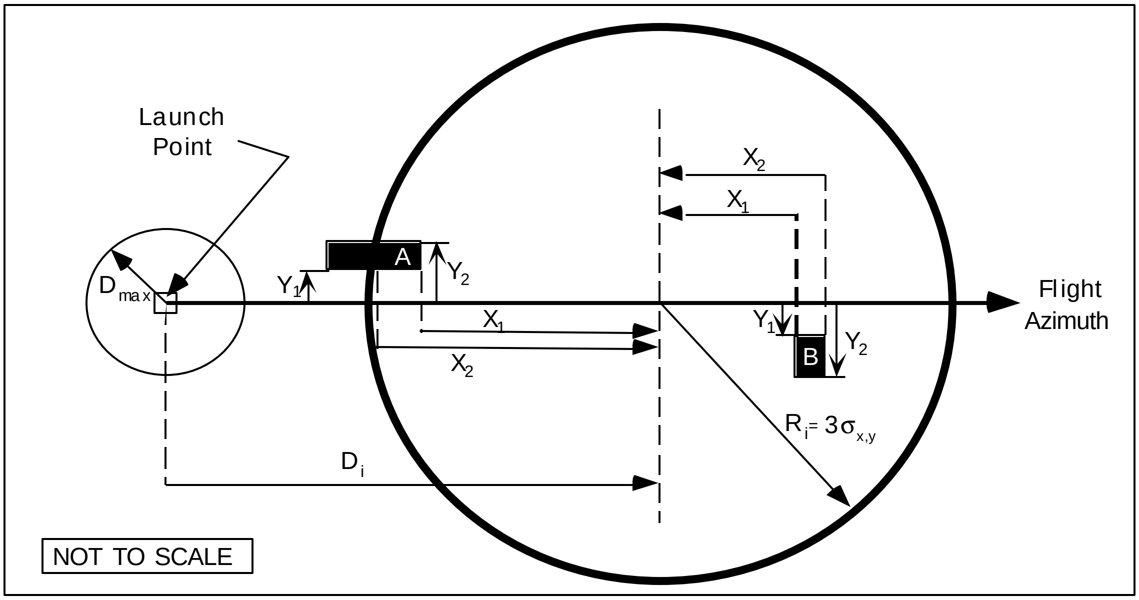

Figure D-2
Intermediate and Final Stage Impact Risk Analysis

(iii) If a populated area intersects the impact dispersion area boundary so that the x_2 or y_2 distance would otherwise extend outside the impact dispersion area, the x_2 or y_2 distance should be set equal to the impact dispersion area radius. The x_2 distance for populated area A in figure D-2 is an example.

(iv) If a populated area intersects the flight azimuth, an applicant shall solve equation D4 by obtaining the solution in two parts. An applicant shall determine, first, the probability between $y_1 = 0$ and $y_2 = a$ and, second, the probability between $y_1 = 0$ and $y_2 = b$, as depicted in figure D-3. The probability P_y is then equal to the sum of the probabilities of the two parts. If a populated area intersects the line that is normal to the flight azimuth on the impact point, an applicant shall solve equation D3 by obtaining the solution in two parts in the same manner as with the values of x.

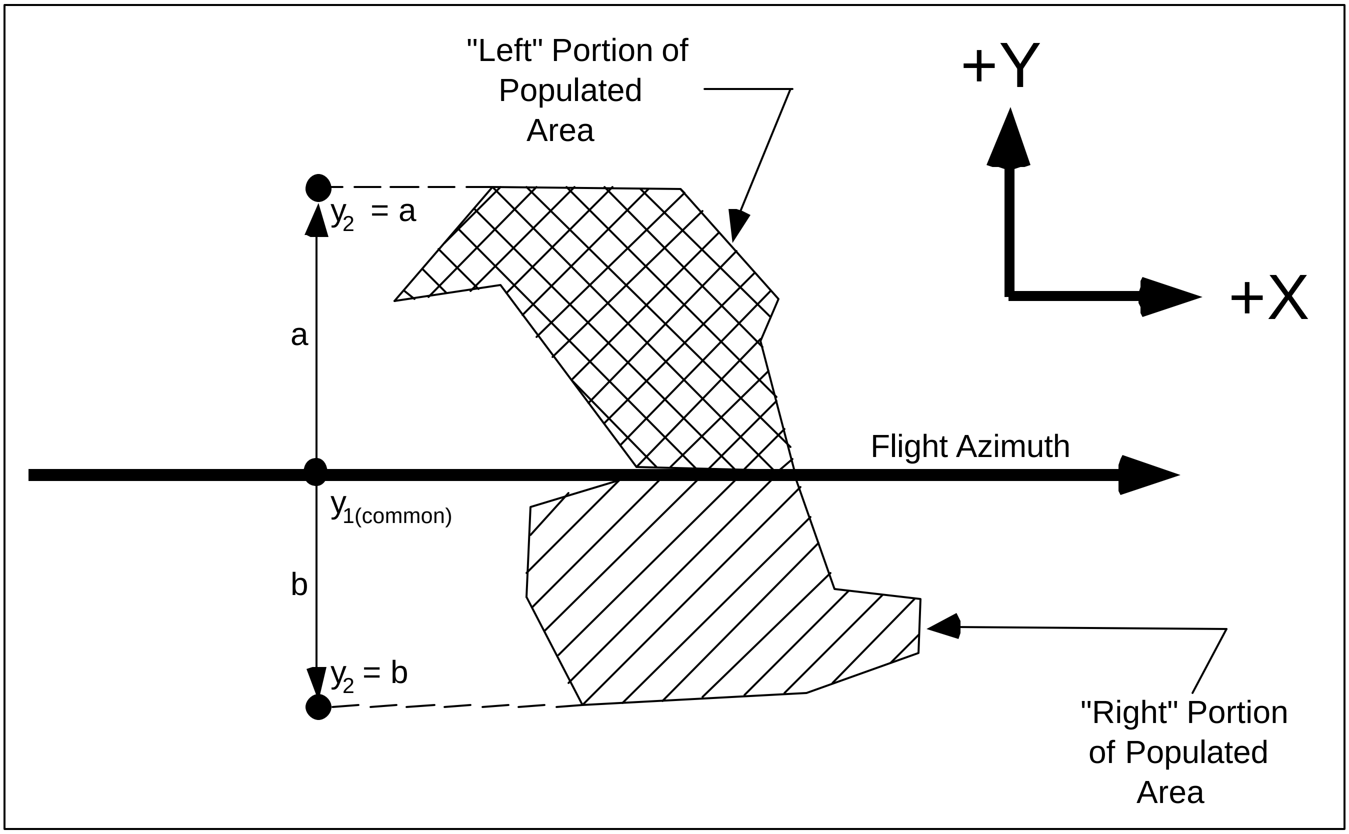

Figure D-3
Flight Azimuth Intersecting a Populated Area

(v) An applicant shall calculate the probability of impact (P_i) for each populated area using the following equation:

$$P_i = P_s \cdot P_x \cdot P_y \qquad \text{(Equation D5)}$$

where: P_s = probability of success = 0.98

(vi) An applicant shall calculate the casualty expectancy for each populated area. E_{ck} is the casualty expectancy for a given populated area as shown in equation D6, where individual populated areas are designated with the subscript "k".

$$E_{ck} = P_i \cdot \left(\frac{A_c}{A_k}\right) \cdot N_k \qquad \text{(Equation D6)}$$

where: $k \in \{1,\ 2,\ 3,\ \ldots\ ,\ n\}$
A_c = casualty area (from table D-1)
A_k = populated area
N_k = population in A_k

Table D-1: Effective Casualty Area(A_c) vs. Impact Range

Impact Range (nm)	Effective Casualty Area (miles^2)
0 - 4	$9x10^{-3}$
5 - 49	$9x10^{-3}$
50 - 1,749	$1.1x10^{-5}$
1,750 - 4,999	$3.6x10^{-6}$
5,000 - more	$3.6x10^{-6}$

(vii) An applicant shall estimate the total risk using the following summation of risk:

$$Ec(\text{Corridor}) = \left(\sum_{k=1}^{n} E_{c_k} \right) \qquad \text{(Equation D7)}$$

(viii) Alternative casualty expectancy (E_C) analysis. An applicant may employ specified variations to the analysis defined by subparagraphs (d)(1)(i) - (vii). Those variations are identified in subparagraphs (viii)(A) through (F) of this paragraph. Subparagraphs (A) through (D) permit an applicant to make conservative assumptions that would lead to an overestimation of E_C compared with the analysis defined by subparagraphs (d)(1)(i) - (vii). In subparagraphs (E) and (F), an applicant that would otherwise fail the analysis prescribed by subparagraphs (d)(1)(i) - (vii) may avoid (d)(1)(i) - (vii)'s overestimation of the probability of impact in each populated area. An applicant employing a variation shall identify the variation used, show and discuss the specific assumptions made to modify the analysis defined by subparagraphs (d)(1)(i) - (vii), and demonstrate how each assumption leads to overestimation of the corridor E_C compared with the analysis defined by subparagraphs (d)(1)(i) - (vii).

(A) Assume that P_x and P_y have a value of 1.0 for all populated areas.

(B) Combine populated areas into one or more larger populated areas, and use a population density for the combined area or areas equal to the most densely populated area.

(C) For any given populated area, assume P_x has a value of one.

(D) For any given populated area, assume P_y has a value of one.

(E) For a given populated area, divide the populated area into smaller rectangles, determine P_i for each individual rectangle, and sum the individual impact probabilities to determine P_i for the entire populated area.

(F) For a given populated area, use the ratio of the populated area to the area of the P_i rectangle used in the subparagraph (d)(1)(i) - (vii) analysis.

(2) If the estimated expected casualty does not exceed $30x10^{-6}$, the FAA will approve the launch point.

(3) If the estimated expected casualty exceeds $30x10^{-6}$, then an applicant may modify its proposal and then repeat the impact risk analysis in accordance with this appendix D. If no set of impact dispersion areas exist which satisfy the FAA's risk threshold, the applicant's proposed launch site will fail the launch site location review.

Appendix E to Part 420
Tables for Explosive Site Plan

Table E-1: Quantity Distance Requirements for Solid Explosives

Quantity (lbs.) (Over)	Quantity (lbs.) (Not Over)	Public Area Distance (ft.) for Division 1.1	Public Area Distance (ft.) for Division 1.3	Intraline Distance (ft.) for Division 1.1	Intraline Distance (ft.) for Division 1.3
0	1,000	1,250	75	$D = 18\ W^{1/3}$	50
1,000	5,000		115		75
5,000	10,000		150		100
10,000	20,000		190		125
20,000	30,000		215		145
30,000	40,000	$D = 40\ W^{1/3}$	235		155
40,000	50,000		250		165
50,000	60,000		260		175
60,000	70,000		270		185
70,000	80,000		280		190
80,000	90,000		195		195
90,000	100,000		300		200
100,000	200,000	$D = 2.42\ W^{0.577}$	375		250
200,000	250,000		413		275
250,000	300,000	$D = 50\ W^{1/3}$	450		300
300,000	400,000		525		350
400,000	500,000		600		400
500,000	1,000,000		800		500
Greater than 1,000,000		$D = 50\ W^{1/3}$	$D = 8\ W^{1/3}$		$D = 5\ W^{1/3}$

"D" equals the minimum separation distance in feet.
"W" equals the NEW of propellant.

Table E-2: Liquid Propellant Explosive Equivalents

Propellant Combinations	Explosive Equivalent
LO_2/LH_2	The larger of : $8W^{2/3}$ where W is the weight of LO2/LH2, or 14% of W
LO_2/LH_2 + LO_2/RP-1	Sum of (20% for LO_2/RP-1) + the larger of: $8W^{2/3}$ where W is the weight of LO2/LH2, or 14% of W
LO_2/RP-1	20% of W up to 500,000 pounds plus 10% of W over 500,000 pounds, where W is the weight of LO2/RP-1.
N_2O_4/N_2H_4 (or UDMH or UDMH/N_2H_4 Mixture)	10% of W, where W is the weight of the propellant.

Table E-3: Propellant Hazard and Compatibility Groupings and Factors to be Used When Converting Gallons of Propellant into Pounds

Propellant	Hazard Group	Compatibility Group	Pounds/gallon	At temperature °F
Hydrogen Peroxide	II	A	11.6	68
Hydrazine	III	C	8.4	68
Liquid Hydrogen	III	C	0.59	-423
Liquid Oxygen	II	A	9.5	-297
Nitrogen Tetroxide	I	A	12.1	68
RP-1	I	C	6.8	68
UDMH	III	C	6.6	68
UDMH/Hydrazine	III	C	7.5	68

Table E-4: Hazard Group I

Pounds of Propellant		Public area and incompatible	Intragroup and compatible	Pounds of Propellant		Public area and incompatible	Intragroup and compatible
Over	Not Over	Distance in feet	Distance in feet	Over	Not Over	Distance in feet	Distance in feet
0	100	30	25	5,000	6,000	80	60
100	200	35	30	6,000	7,000	85	65
200	300	40	35	7,000	8,000	85	65
300	400	45	35	8,000	9,000	90	70
400	500	50	40	9,000	10,000	90	70
500	600	50	40	10,000	15,000	95	75
600	700	55	40	15,000	20,000	100	80
700	800	55	45	20,000	25,000	105	80
800	900	60	45	25,000	30,000	110	85
900	1,000	60	45	30,000	35,000	110	85
1,000	2,000	65	50	35,000	40,000	115	85
2,000	3,000	70	55	40,000	45,000	120	90
3,000	4,000	75	55	45,000	50,000	120	90
4,000	5,000	80	60	50,000	60,000	125	95

Table E-4 (Continued): Hazard Group I

Pounds of Propellant		Public area and incompatible	Intragroup and compatible	Pounds of Propellant		Public area and incompatible	Intragroup and compatible
Over	Not Over	Distance in feet	Distance in feet	Over	Not Over	Distance in feet	Distance in feet
60,000	70,000	130	95	500,00	600,000	185	140
70,000	80,000	130	100	600,000	700,000	190	145
80,000	90,000	135	100	700,000	800,000	195	150
90,000	100,000	135	105	800,000	900,000	200	150
100,000	125,000	140	110	900,000	1,000,000	205	155
125,000	150,000	145	110	1,000,000	2,000,000	235	175
150,000	175,000	150	115	2,000,000	3,000,000	255	190
175,000	200,000	155	115	3,000,000	4,000,000	265	200
200,000	250,000	160	120	4,000,000	5,000,000	275	210
250,000	300,000	165	125	5,000,000	6,000,000	285	215
300,000	350,000	170	130	6,000,000	7,000,000	295	220
350,000	400,000	175	130	7,000,000	8,000,000	300	225
400,000	450,000	180	135	8,000,000	9,000,000	305	230
450,000	500,000	180	135	9,000,000	10,000,000	310	235

Table E-5: Hazard Group II

Pounds of propellant		Public area and incompatible	Intragroup and compatible	Pounds of propellant		Public area and incompatible	Intragroup and compatible
Over	Not Over	Distance in feet	Distance in feet	Over	Not Over	Distance in feet	Distance in feet
0	100	60	30	50,000	60,000	250	125
100	200	75	35	60,000	70,000	255	130
200	300	85	40	70,000	80,000	260	130
300	400	90	45	80,000	90,000	265	135
400	500	100	50	90,000	100,000	270	135
500	600	100	50	100,000	125,000	285	140
600	700	105	55	125,000	150,000	295	145
700	800	110	55	150,000	175,000	305	150
800	900	115	60	175,000	200,000	310	155
900	1,000	120	60	200,000	250,000	320	160
1,000	2,000	130	65	250,000	300,000	330	165
2,000	3,000	145	70	300,000	350,000	340	170
3,000	4,000	150	75	350,000	400,000	350	175
4,000	5,000	160	80	400,000	450,000	355	180
5,000	6,000	165	80	450,000	500,000	360	180
6,000	7,000	170	85	500,000	600,000	375	185
7,000	8,000	175	85	600,000	700,000	385	190
8,000	9,000	175	90	700,000	800,000	395	195
9,000	10,000	180	90	800,000	900,000	405	200
10,000	15,000	195	95	900,000	1,000,000	410	205
15,000	20,000	205	100	1,000,000	2,000,000	470	235
20,000	25,000	215	105	2,000,000	3,000,000	505	255
25,000	30,000	220	110	3,000,000	4,000,000	535	265
30,000	35,000	225	110	4,000,000	5,000,000	555	275
35,000	40,000	230	115	5,000,000	6,000,000	570	285
40,000	45,000	235	120	6,000,000	7,000,000	585	295
45,000	50,000	240	120	7,000,000	8,000,000	600	300
				8,000,000	9,000,000	610	305
				9,000,000	10,000,000	620	310

Table E-6: Hazard Group III

Pounds of Propellant	Pounds of Propellant	Public area and incompatible	Intragroup and compatible	Pounds of Propellant	Pounds of Propellant	Public area and incompatible	Intragroup and compatible
Over	Not Over	Distance in feet	Distance in feet	Over	Not Over	Distance in feet	Distance in feet
0	100	600	30	60,000	70,000	1,200	130
100	200	600	35	70,000	80,000	1,200	130
200	300	600	40	80,000	90,000	1,200	135
300	400	600	45	90,000	100,000	1,200	135
400	500	600	50	100,000	125,000	1,800	140
500	600	600	50	125,000	150,000	1,800	145
600	700	600	55	150,000	175,000	1,800	150
700	800	600	55	175,000	200,000	1,800	155
800	900	600	60	200,000	250,000	1,800	160
900	1,000	600	60	250,000	300,000	1,800	165
1,000	2,000	600	65	300,000	350,000	1,800	170
2,000	3,000	600	70	350,000	400,000	1,800	175
3,000	4,000	600	75	400,000	450,000	1,800	180
4,000	5,000	600	80	450,000	500,000	1,800	180
5,000	6,000	600	80	500,000	600,000	1,800	185
6,000	7,000	600	85	600,000	700,000	1,800	190
7,000	8,000	600	85	700,000	800,000	1,800	195
8,000	9,000	600	90	800,000	900,000	1,800	200
9,000	10,000	600	90	900,000	1,000,000	1,800	205
10,000	15,000	1,200	95	1,000,000	2,000,000	1,800	235
15,000	20,000	1,200	100	2,000,000	3,000,000	1,800	255
20,000	25,000	1,200	105	3,000,000	4,000,000	1,800	265
25,000	30,000	1,200	110	4,000,000	5,000,000	1,800	275
30,000	35,000	1,200	110	5,000,000	6,000,000	1,800	285
35,000	40,000	1,200	115	6,000,000	7,000,000	1,800	295
40,000	45,000	1,200	120	7,000,000	8,000,000	1,800	300
45,000	50,000	1,200	120	8,000,000	9,000,000	1,800	305
50,000	60,000	1,200	125	9,000,000	10,000,000	1,800	310

Table E-7: Distances When Explosive Equivalents Apply

TNT Equivalent Weight of Propellants	Distance in feet	
	To Public Area	Intraline
Not over		Unbarricaded
100	1250	80
200	1250	100
300	1250	120
400	1250	130
500	1250	140
600	1250	150
700	1250	160
800	1250	170
900	1250	180
1,000	1250	190
1,500	1250	210
2,000	1250	230
3,000	1250	260
4,000	1250	280
5,000	1250	300
6,000	1250	320
7,000	1250	340
8,000	1250	360
9,000	1250	380
10,000	1250	400
15,000	1250	450
20,000	1250	490

Table E-7 (continued): Distances When Explosive Equivalents Apply

TNT Equivalent Weight of Propellants	Distance in feet	
	To Public Area	Intraline
Not over		Unbarricaded
25,000	1,250	530
30,000	1,250	560
35,000	1,310	590
40,000	1,370	620
45,000	1,425	640
50,000	1,475	660
55,000	1,520	680
60,000	1,565	700
65,000	1,610	720
70,000	1,650	740
75,000	1,685	770
80,000	1,725	780
85,000	1,760	790
90,000	1,795	800
95,000	1,825	820
100,000	1,855	830
125,000	2,115	900
150,000	2,350	950
175,000	2,565	1,000
200,000	2,770	1,050